

Multi-TeV (brane-world) Dark Matter: a brief overview

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4th IBS-MultiDark-IPPP Workshop

Outlook

- Model independent Multi-TeV Dark Matter (DM):
 - ➡ motivation & previous works (Galactic Center)
 - ➡ TeV DM searches in dwarf irregular galaxies with the High Altitude Water Cherenkov (HAWC) Observatory
 - ➡ Multi-wavelength prospects and the Square Kilometre Array (SKA) (Draco dwarf spheroidal galaxy)
- Multi-TeV brane-world DM
- Conclusions

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Dark Matter searches

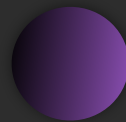
DM Model
and spin
dependent
 $\text{GeV} < m_{\text{DM}} < \text{TeV}$

DM Model
Independent
and
 $\text{MeV} < m_{\text{DM}} < \text{PeV}$

Indirect detection



DM

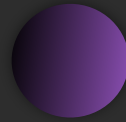


χ Particles

SM

(quarks, bosons, leptons)

DM



SM

Energy $\equiv \chi$ Mass

Channel
 $\equiv$
 χ Model

DM Model
dependent
and
 $\text{GeV} < m_{\text{DM}} < \text{TeV}$

Detection at Colliders (CERN, LHC etc..)



Direct detection

(Underground experiments)

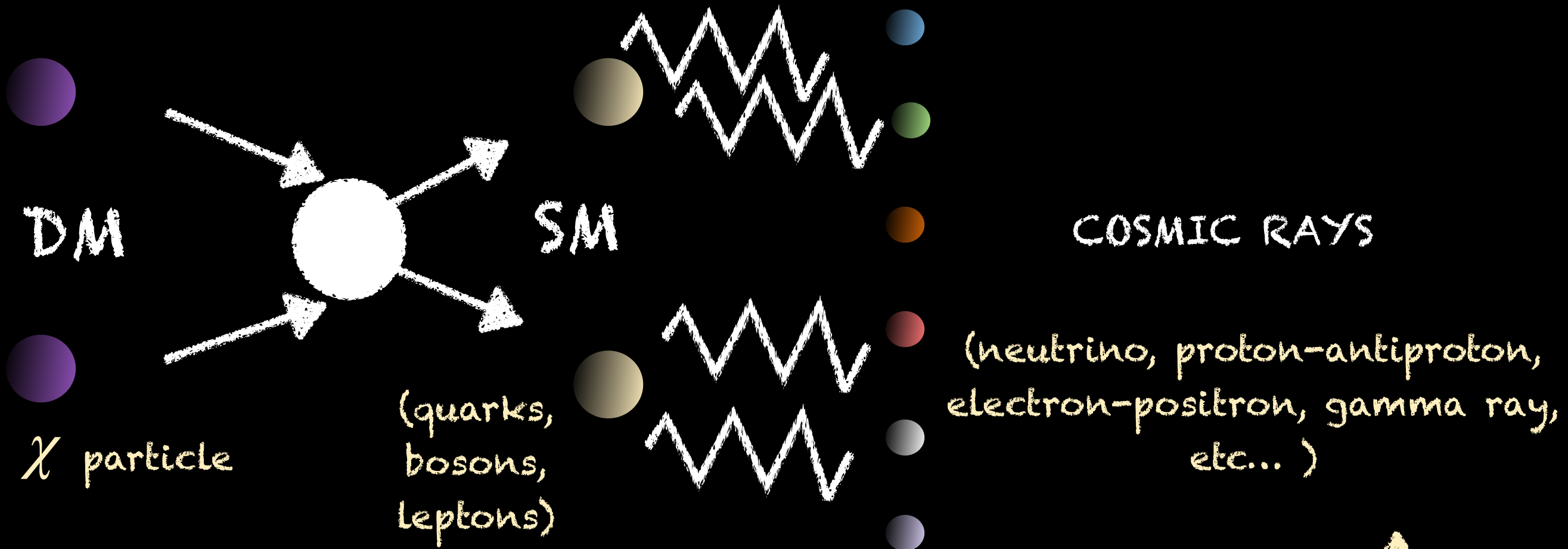


Motivation

- No detection of any DM signatures at colliders below few TeV
- Strong tension emerges between the DAMA/NaI and DAMA/LIBRA claim and the null results from several underground experiments, such as CDMS, XENON10, CRESST I, CoGeNT, TEXONO, and Super-Kamiokande
- Many claims of prospective gamma-ray signatures from MeV-GeV DM candidates (Fermi-LAT GeV-excess, emission lines, etc...)
- We are in the era of TeV observatories!

No conclusive evidence for WIMPs at GeV so far.

How do we search for DM indirectly?



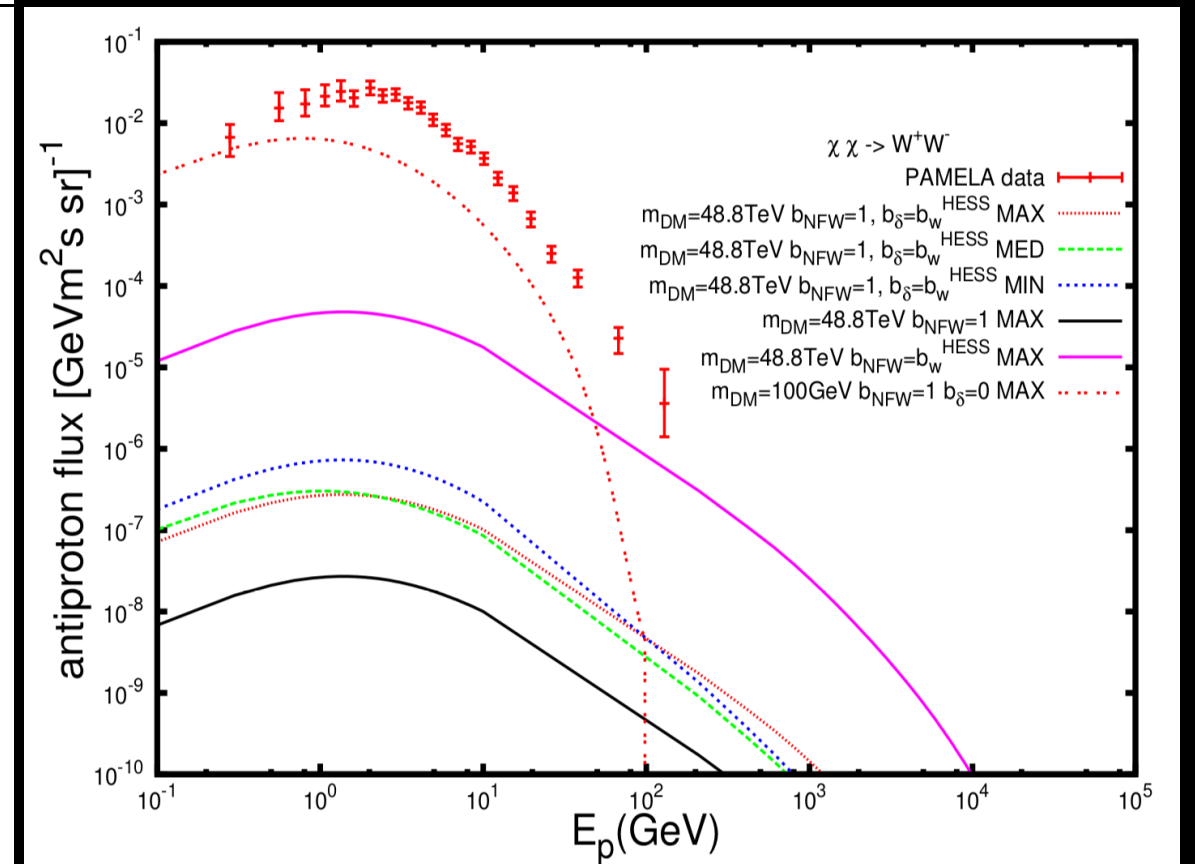
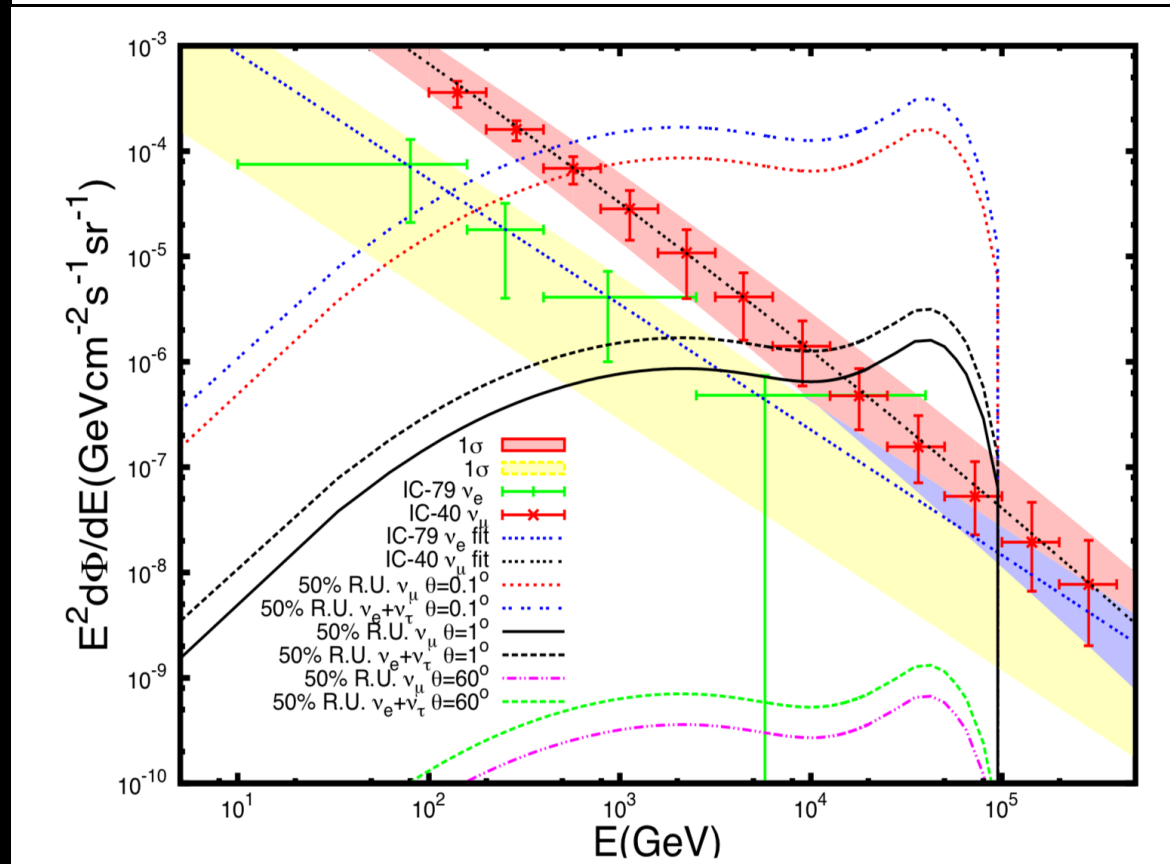
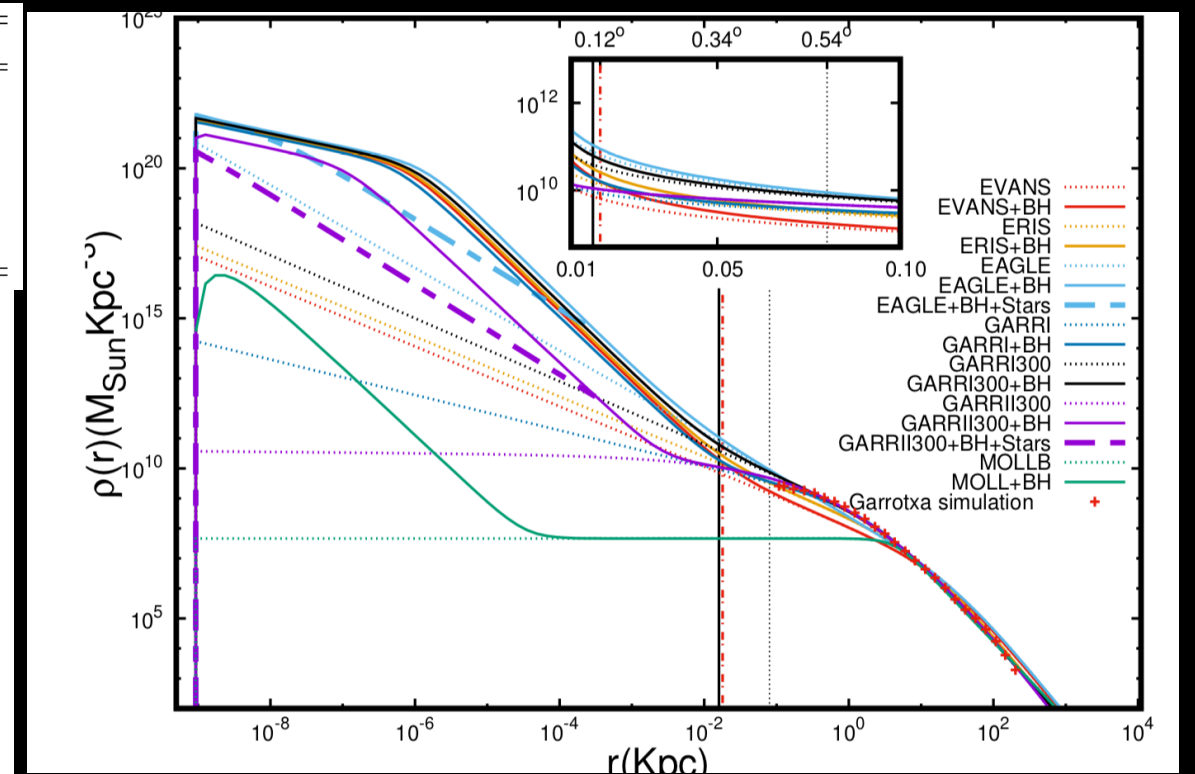
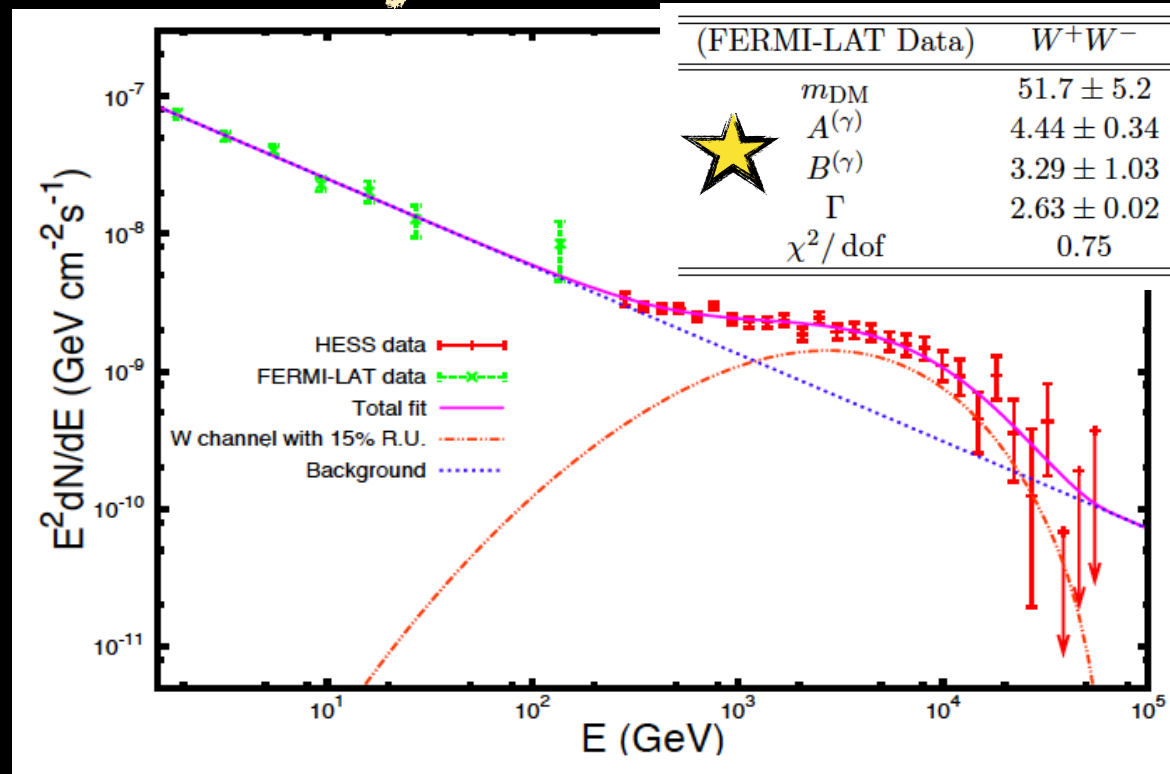
MULTIMESSENGER APPROACH:

$$\sum_{a=1}^2 \frac{\kappa_{\mathbf{cr}}^{(a)}}{4\pi m_{DM-\chi}^a} \cdot \sum_i^{\text{SM channels}} \frac{\zeta_i^{(a)}}{a} \frac{dN_i^{(\mathbf{cr})}}{dE} \cdot \eta_{\mathbf{cr}} = \frac{d\Phi_{\mathbf{cr}-DM}}{dE}$$

Previous works: the Galactic Center

(gamma rays)

(DM distribution)



Previous works

- Model independent Multi-TeV DM candidate well fits the GC cut-off by HESS (2012) -> Multimessenger analyses are in agreement with neutrino (2014) & antiproton (2015) data...

plenty of recent data and different analyses about related topics that should be mentioned.. updated analyses required for a comprehensive discussion... work in progress!

- Such a model requires a 10^3 enhancement, which could be produced by a black hole induced DM spike

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TeV DM @ dwarf irregular galaxies

Dwarf spheroidal (dSph) galaxies



The Draco Spheroidal Dwarf Galaxy

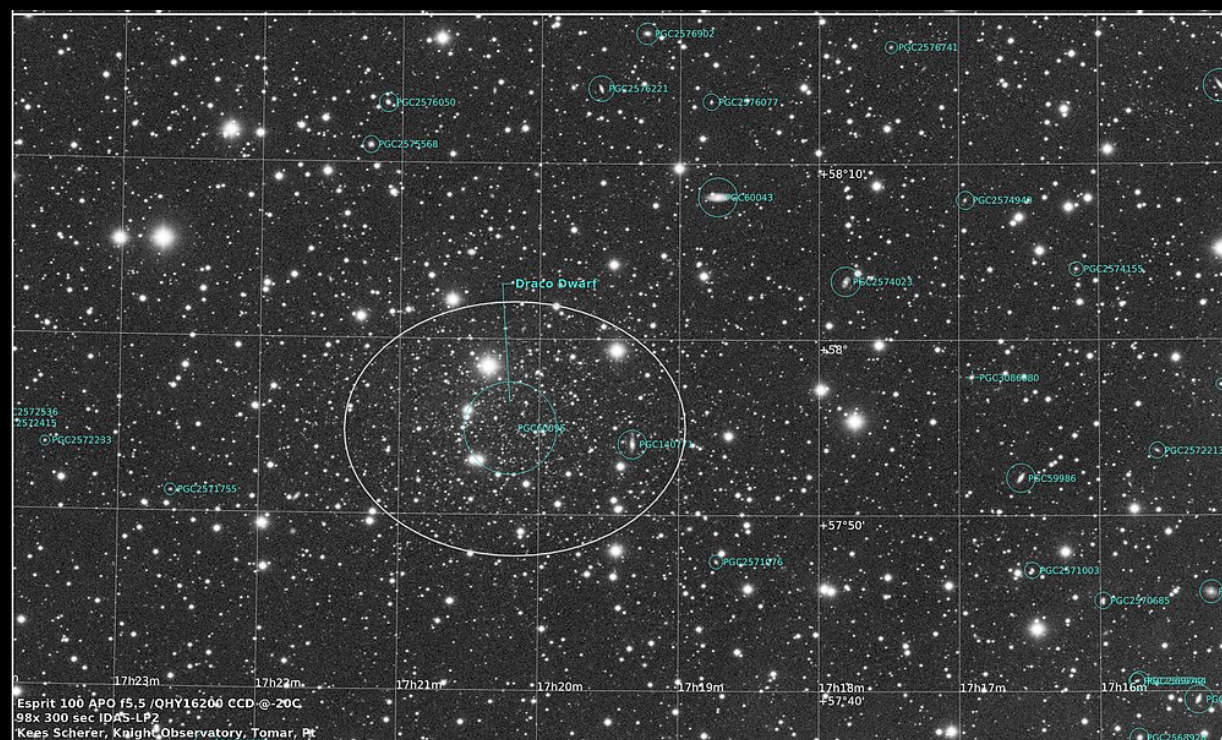
Credit: Keesscherer [CC BY-SA 4.0
(<https://creativecommons.org/licenses/by-sa/4.0/>)]

Dwarf irregular (dIrr) galaxies

TeV DM @ dwarf irregular galaxies

Dwarf spheroidal (dSph) galaxies

Dwarf irregular (dIrr) galaxies

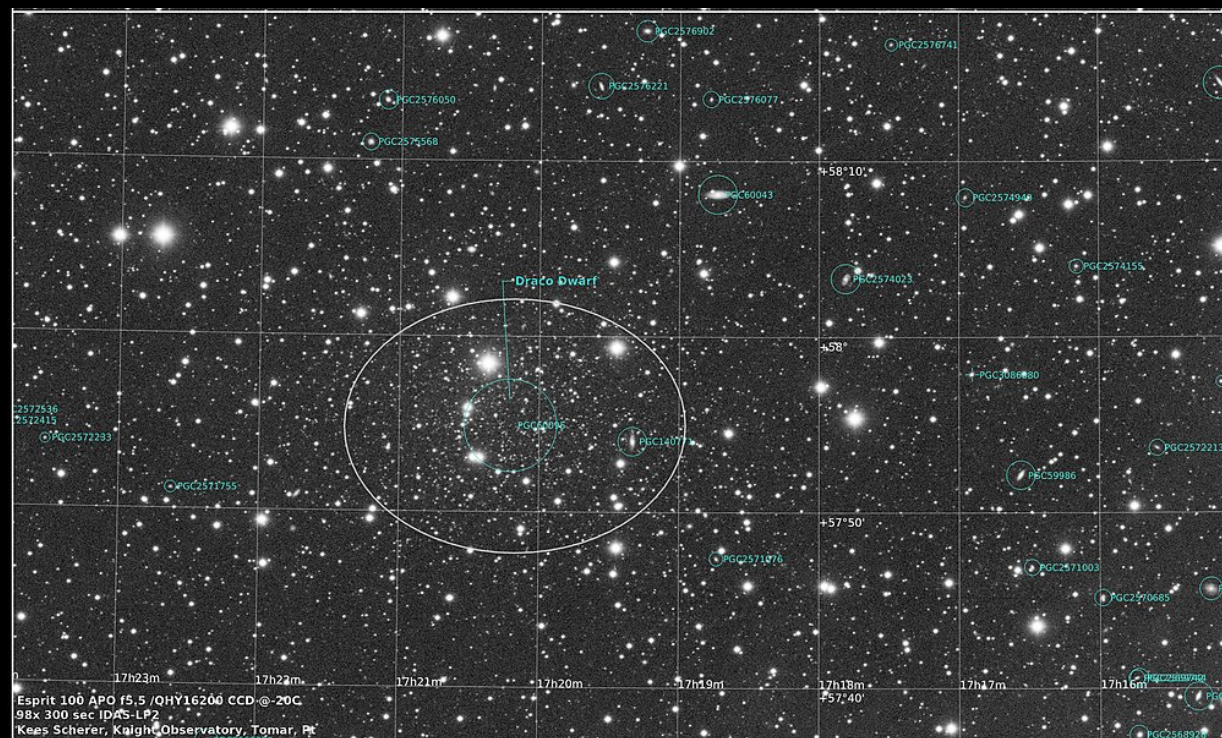


The Draco Spheroidal Dwarf Galaxy

Credit: Keesscherer [CC BY-SA 4.0
(<https://creativecommons.org/licenses/by-sa/4.0>)]

TeV DM @ dwarf irregular galaxies

Dwarf spheroidal (dSph) galaxies



The Draco Spheroidal Dwarf Galaxy

Credit: Keesscherer [CC BY-SA 4.0
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Dwarf irregular (dIrr) galaxies

The WLM galaxy on the edge of the Local Group

Credit: ESO

TeV DM @ dwarf irregular galaxies

Dwarf spheroidal (dSph) galaxies

Milky Way satellites
 $d < 0.5$ Mpc

Pressure supported objects

(Jeans theory - tidal stripping - phase space function)

DM dominated objects $M_{\text{halo}} 10^6 - 10^8$

10^{14} (Segue 2) $< J\text{-factors} < 10^{19}$ (Draco)
(within the uncertainty)

Old star population
and negligible astrophysical background
in gamma rays

**Well-know targets
for indirect searches of DM**

Dwarf irregular (dIrr) galaxies

Local Volume galaxies
 $0.5 \text{ Mpc} < d < 10 \text{ Mpc}$

Rotationally supported objects
(rotation curve)

DM dominated objects $M_{\text{halo}} 10^8 - 10^{10}$

$10^{14} < J\text{-factors} < 10^{18}$

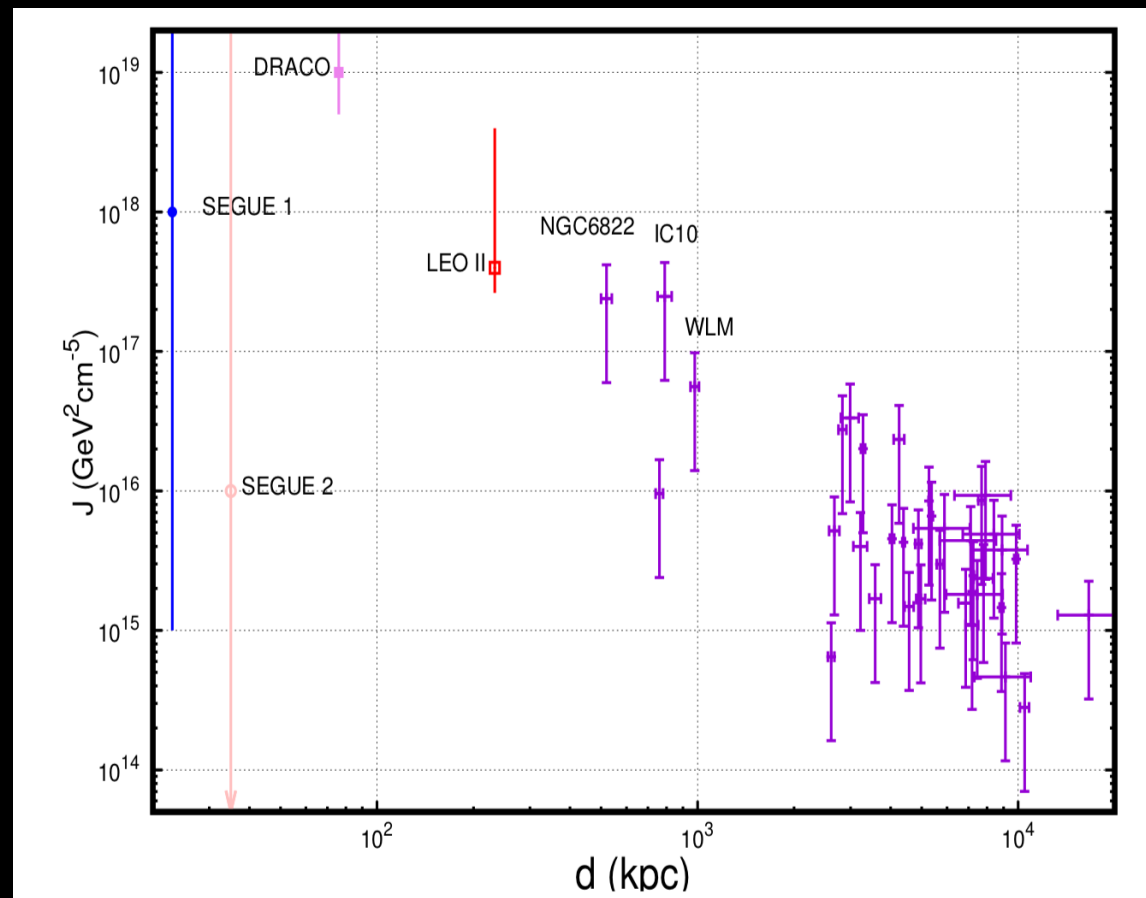
Previous work: Star forming region
and negligible astrophysical background
in gamma-rays? **Yes!**

VG, E. Karukes, P. Salucci, Phys. Rev. D 96, 083001 (2017)

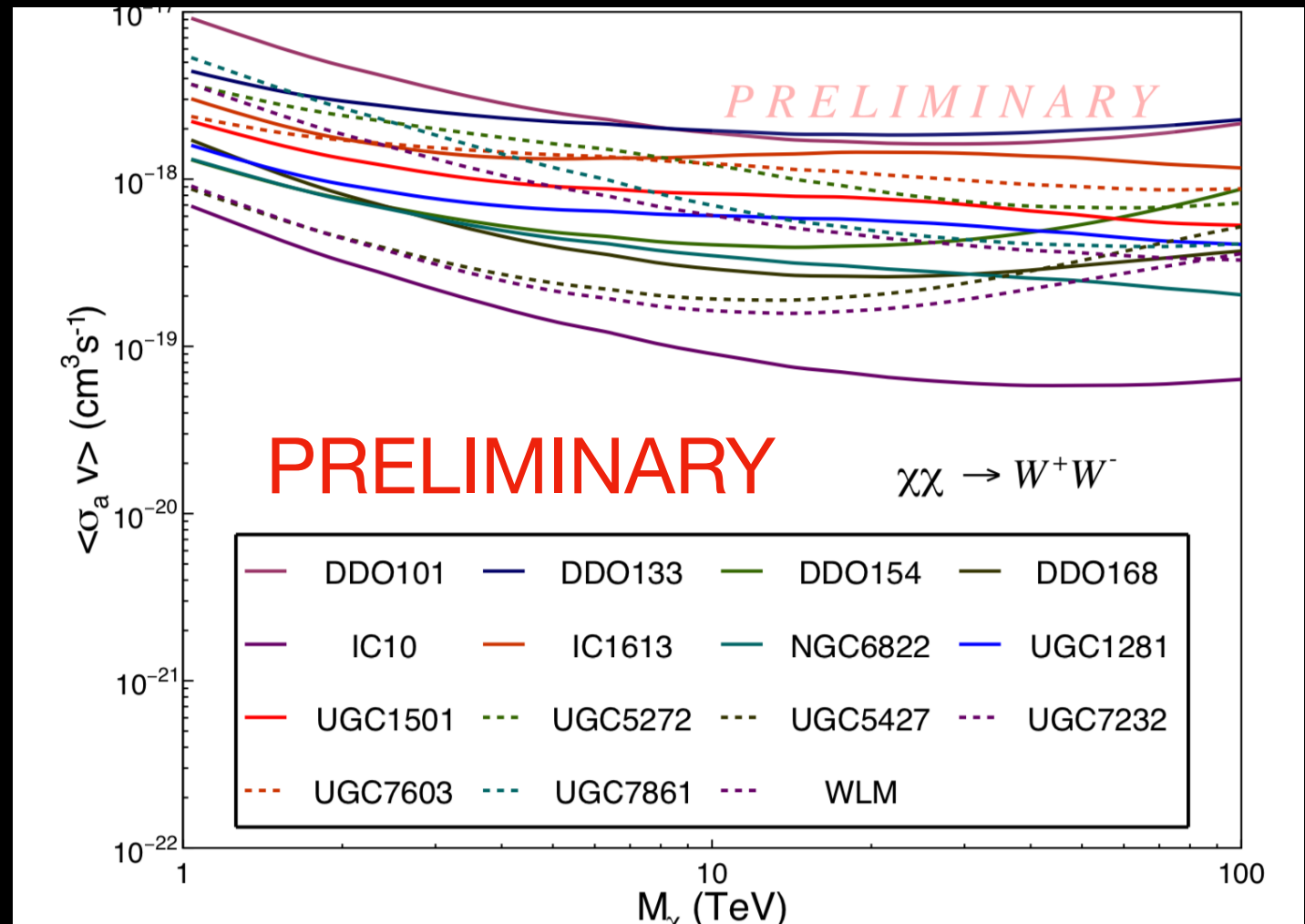
**never analyzed
in the context of gamma-ray DM searches**

TeV DM with HAWC @ dIrrs

- HAWC Observatory (Mexico) with large sky coverage
- No detection of TeV gamma-ray signal from dIrrs
- Point-like analysis developed for dSphs and applied to dIrr galaxies



VG, E. Karukes, P. Salucci, Phys. Rev. D 96, 083001 (2017)



S. H. Cadena, R. Alfaro, A. Sandoval, E. Belmont, H. León, V. G., E. Karukes, P. Salucci for the HAWC Collaboration, HAWC-ICRC/2017/36. (2017)

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Multi-wavelength prospects

After injection e^+/e^- travel following the diffusion equation:

Diffusion coefficient: $D(\mathbf{r}, E) \sim D(E) = D_0 E^\delta$ Energy loss term: Source term:

$$-\nabla \cdot [D(\mathbf{r}, E) \nabla \psi] - \frac{\partial}{\partial E} [b(\mathbf{r}, E) \psi] = Q_e(\mathbf{r}, E)$$

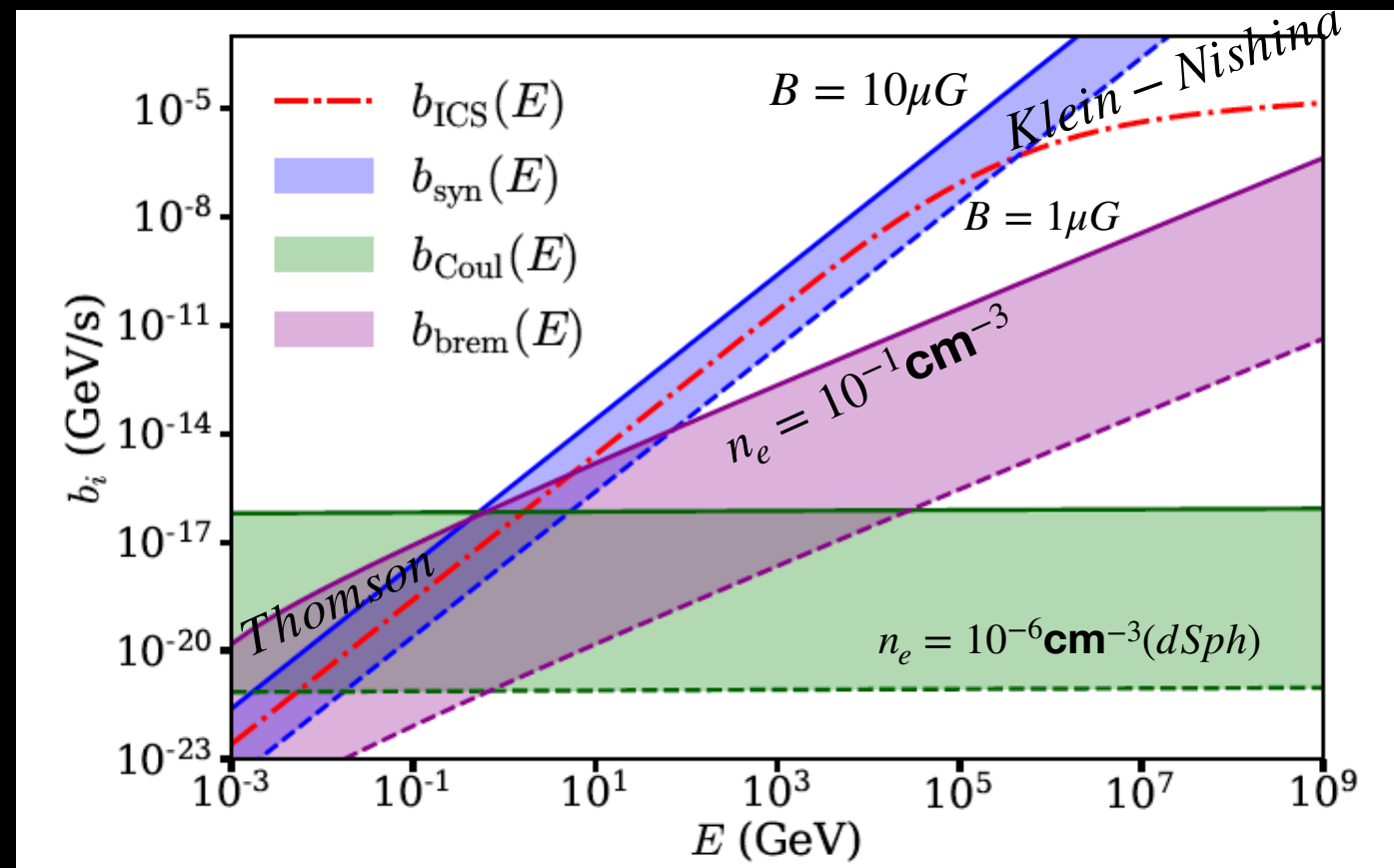
Number density after propagation

$$b(\mathbf{r}, E) = b_{\text{brem}}(E) + b_{\text{Coul}}(E) + b_{\text{ICS}}(E) + b_{\text{syn}}(\mathbf{r}, E)$$

$$b_{\text{brem}}(E) = 1.51 \cdot 10^{-16} n_e E [\log(E/m_e) + 0.36]$$

$$b_{\text{syn}}(\mathbf{r}, E) = 0.0254 \cdot 10^{-4} B^2(\mathbf{r}) E^2$$

$$b_{\text{Coul}}(E) = 6.13 \cdot 10^{-16} n_e [1 + \log(E/n_e m_e)/75]$$



Multi-wavelength prospects: Draco dSph

Emissivity

$$\psi(\mathbf{r}, E) = \frac{1}{b(\mathbf{r}, E)} \int_E^M dE_s G(r, E, E_s) Q_e(\mathbf{r}, E) \rightarrow j_\nu(\mathbf{r}, z) = \int_E^M dE (\psi_{e^+} + \psi_{e^-}) P_{\text{syn}}(\nu, \mathbf{r}, E, z) 2 \int_E^M dE \psi(\mathbf{r}, E) P_{\text{syn}}(\nu, \mathbf{r}, E, z)$$

Green's function

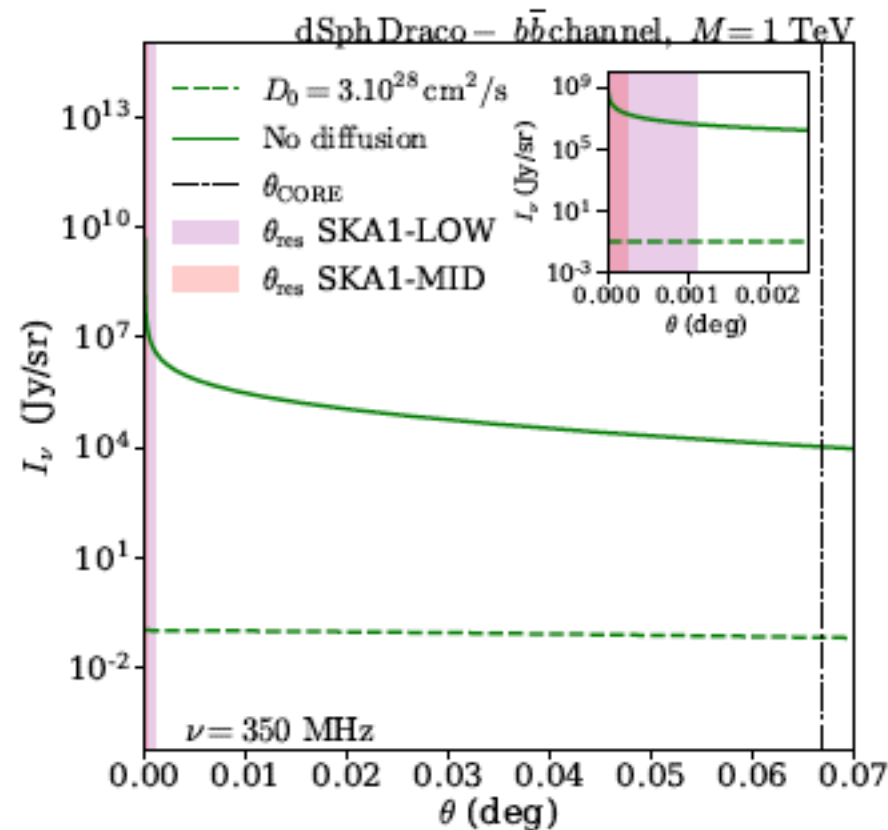
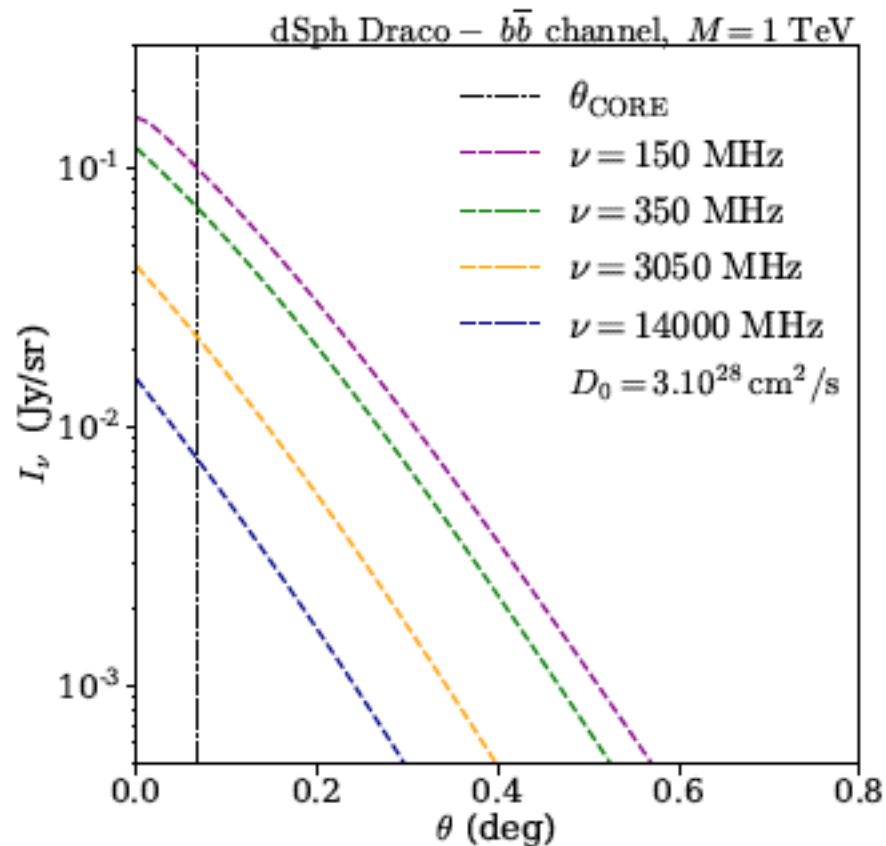
Power of emission: $P_{\text{syn}}(\nu, \mathbf{r}, E, z) = \int_0^\pi d\alpha \frac{\sin^2 \alpha}{4\pi\epsilon_0} \frac{\sqrt{3}e^3 B(\mathbf{r})}{m_e c} F_i \left(\frac{\nu(1+z)}{\nu_c(\mathbf{r}, E) \sin \alpha} \right)$

Source term: $Q_e(\mathbf{r}, E) = \frac{1}{2} \langle \sigma v \rangle \left(\frac{\rho_{\text{DM}}(\mathbf{r})}{M} \right)^2 \sum_j \beta_j \frac{dN_e^j}{dE}$

$$F_i(s) = s \int_s^\infty d\xi K_{\frac{5}{3}}(\xi) \simeq \frac{5}{4} s^{\frac{1}{3}} \exp(-s) (648 + s^2)^{1/12}$$

$$\nu_c(\mathbf{r}, E) = \frac{3eB(\mathbf{r})}{4\pi m_e} \gamma^2(E)$$

$$B(r) = B_0 \exp(-r/r_c)$$



Specific Intensity

$$I_\nu(\theta, z) = \int_{\text{l.o.s.}} dl \frac{j_\nu(l, \theta, z)}{4\pi}$$

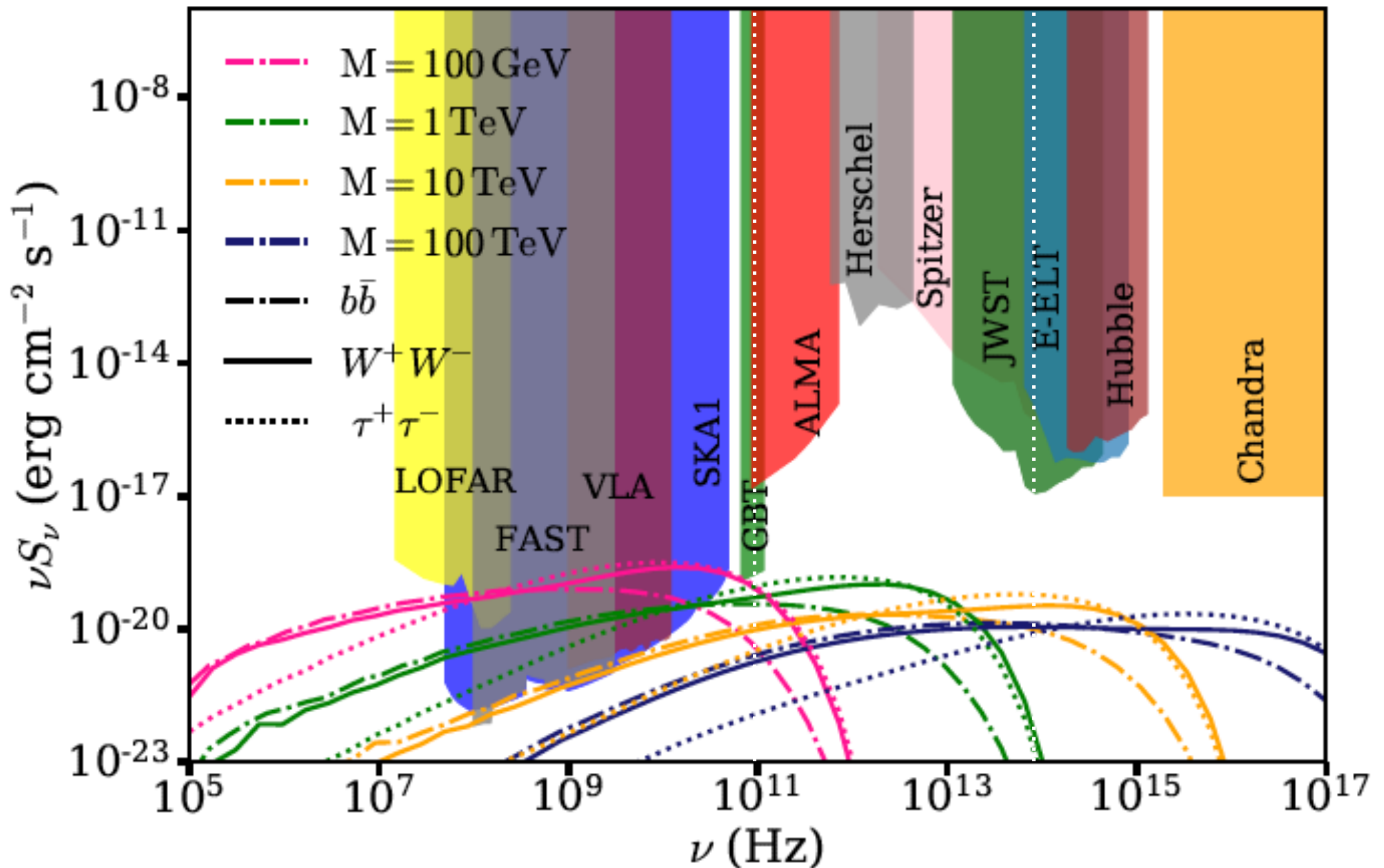
Multi-wavelength prospects: Draco dSph

Flux density

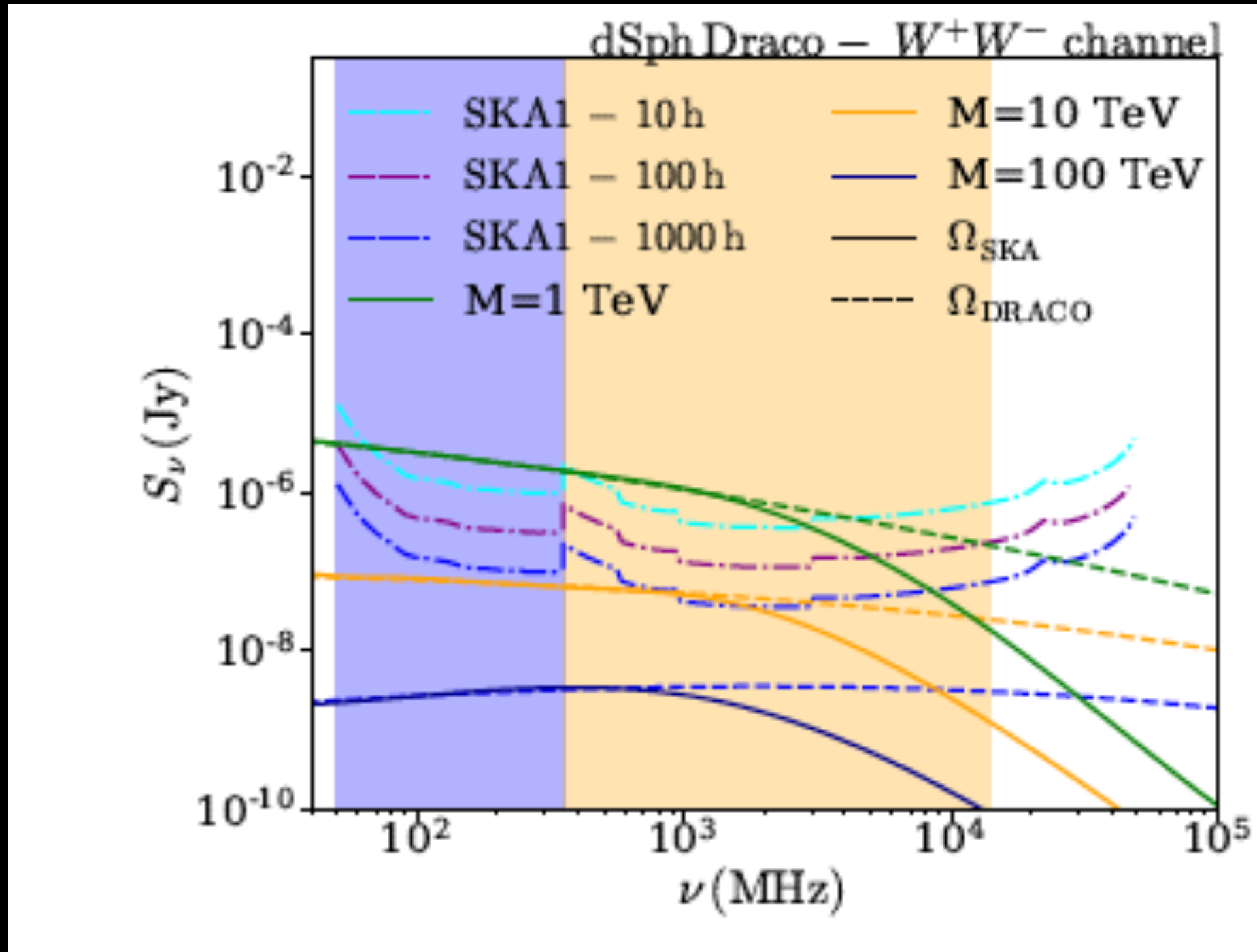
$$S_\nu(z) = \int_{\Omega} d\Omega I_\nu(\theta, z)$$

J. A. R. Cembranos, A. de la Cruz-Dombriz, V. G. , M. Mendez-Isla arXiv:1905.11154, submitted

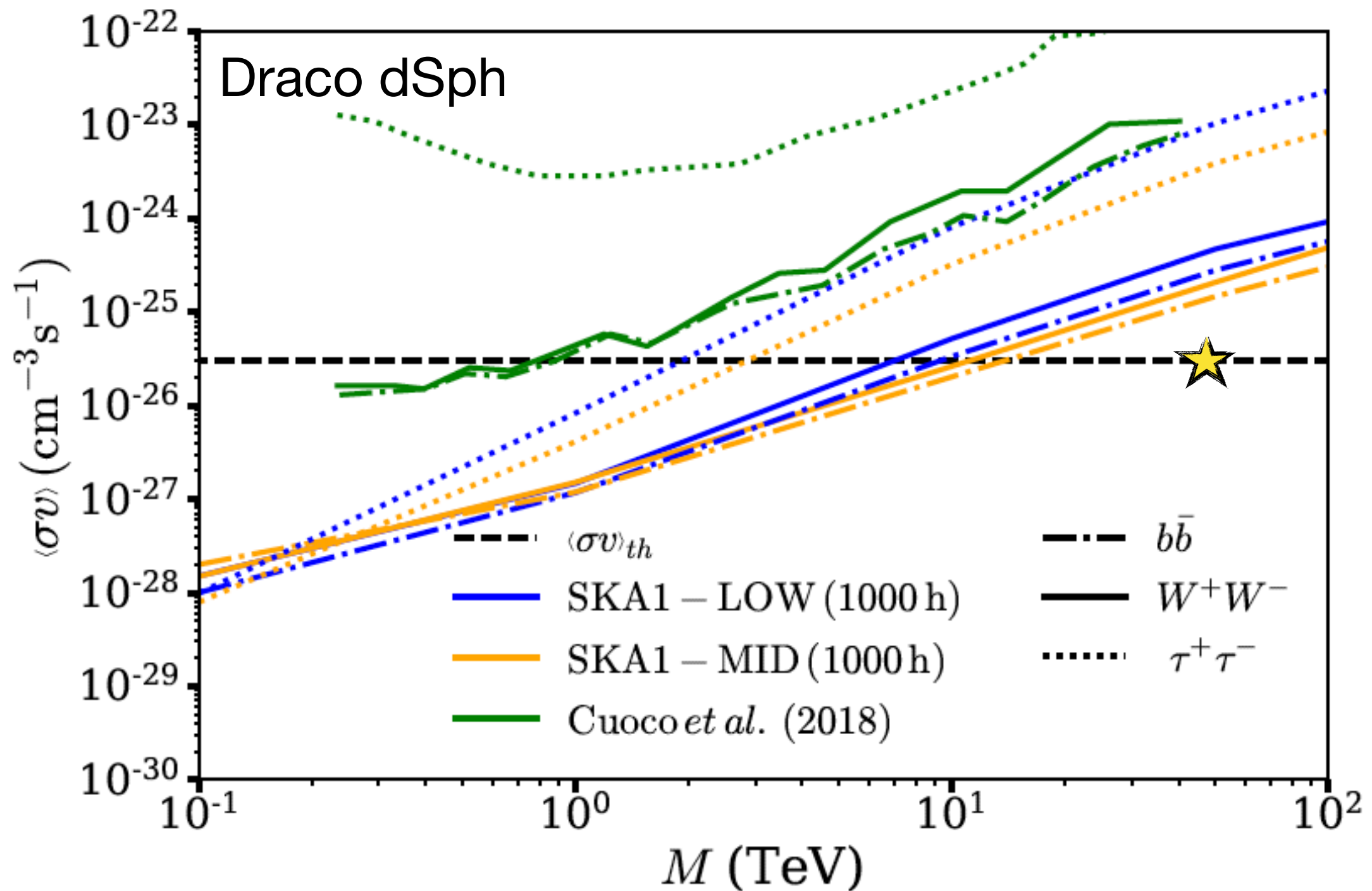
(Model independent
synchrotron emission)



Multi-wavelength prospects: Draco dSph



Multi-wavelength prospects: Draco dSph



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Multi-TeV DM candidates

- Brane-world dark matter

(e.g. J. A. R. Cembranos, A. Dobado and A. L. Maroto , Phys.Rev.D68:103505,2003)

- Heavy Minimal Dark Matter

(e.g. C. Garcia-Cely, A. Ibarra, A. S. Lamperstorfer, M. H.G. Tytgat, JCAP 1510 (2015) no.10, 058;
A. Cuoco, J. Heisig, M. Korsmeier, M. Krämer, JCAP 1804 (2018) no.04, 004)

- Inverse Seesaw and Portal Dark Matter

(e.g. C. Pongkitivanichkul, N. Thongyoi, P. Uttayarat, arXiv:1905.13224)

The branon DM candidate

$$\alpha = 1 \dots N$$

$$\mathcal{L}_{Br} = \frac{1}{2} g^{\mu\nu} \partial_\mu \pi^\alpha \partial_\nu \pi^\alpha - \frac{1}{2} m_{\text{DM}}^2 \pi^\alpha \pi^\alpha + \frac{1}{8f^4} \left(4 \partial_\mu \pi^\alpha \partial_\nu \pi^\alpha - m_{\text{DM}}^2 \pi^\alpha \pi^\alpha g_{\mu\nu} \right) T^{\mu\nu}$$

- ✓ Branons are mass eigenstates of the fluctuations in the extra-space directions

-> massive particles

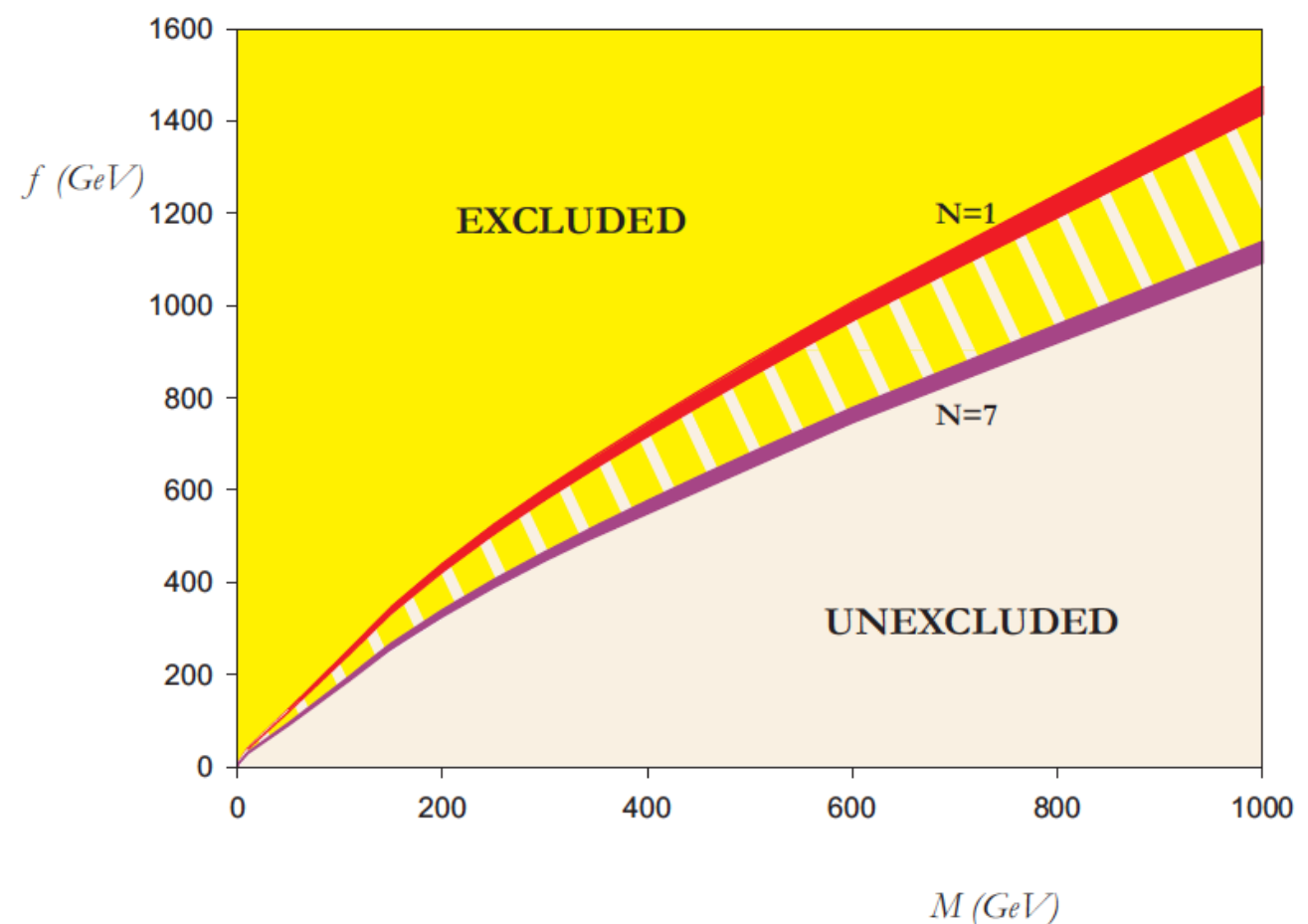
- ✓ Their couplings are suppressed by the tension f^4

-> weakly interacting

Natural
WIMP
candidate

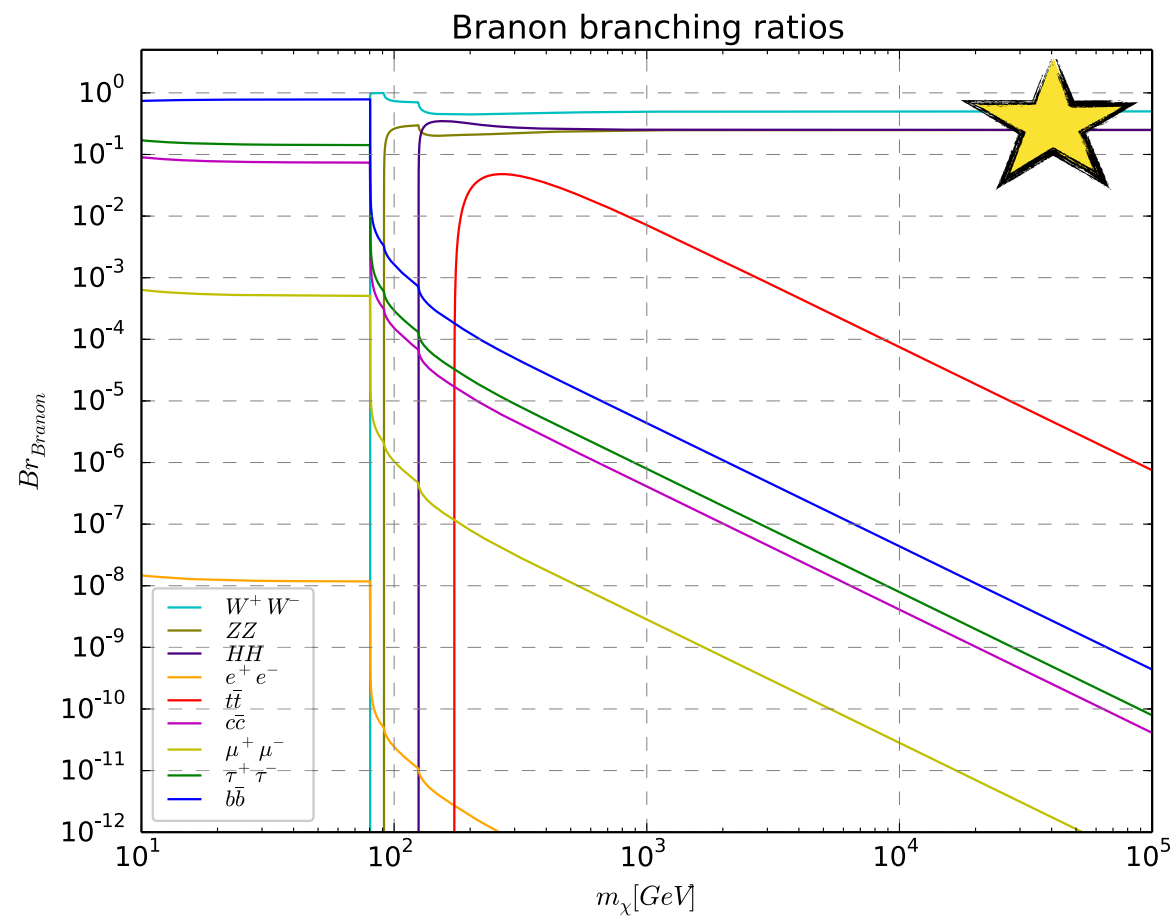
Thermal candidate

J.A.R. Cembranos, A. Dobado, A.L. Maroto, Phys.Rev.D68:103505,2003

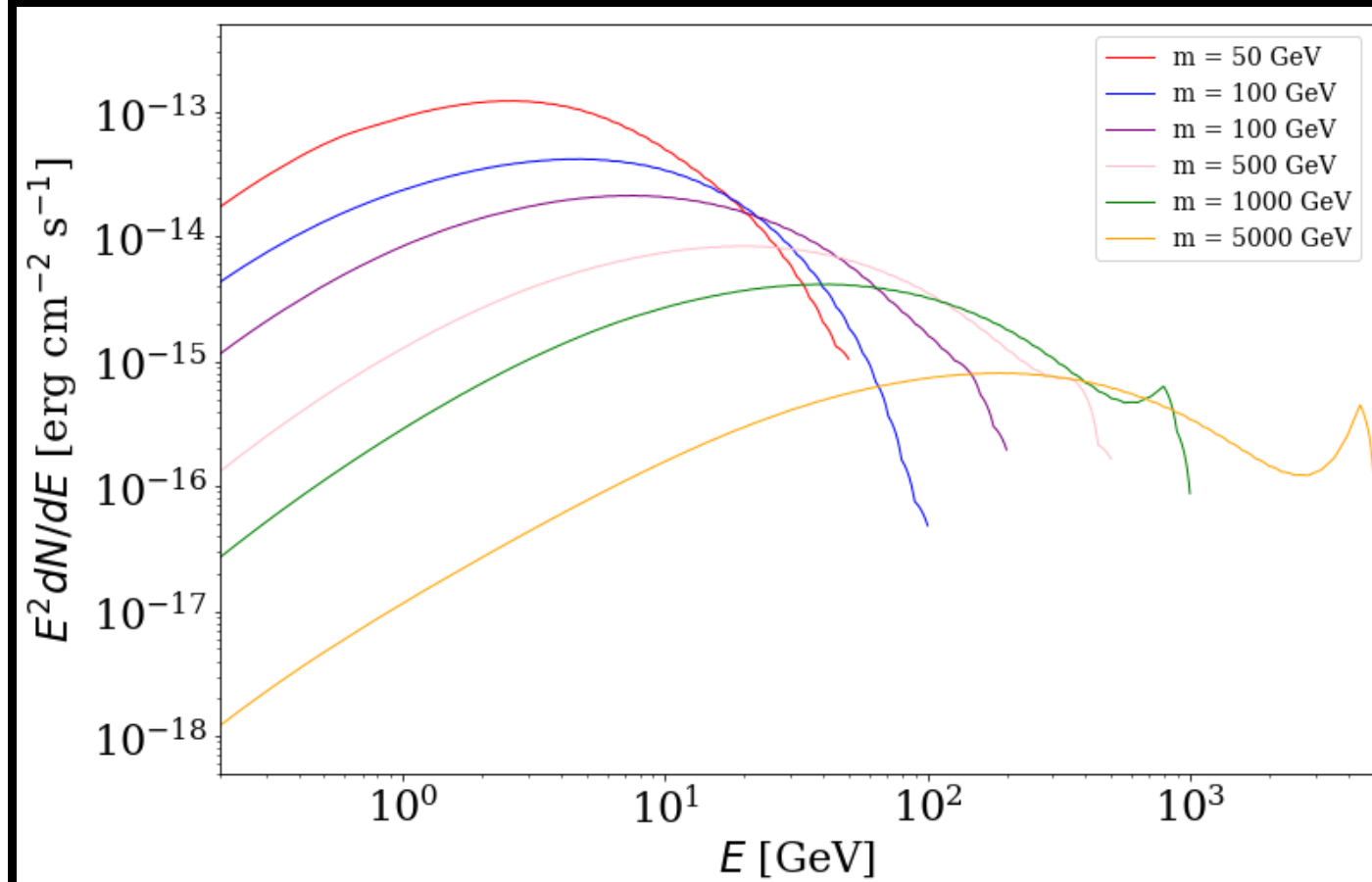


The branon DM feature: gamma rays

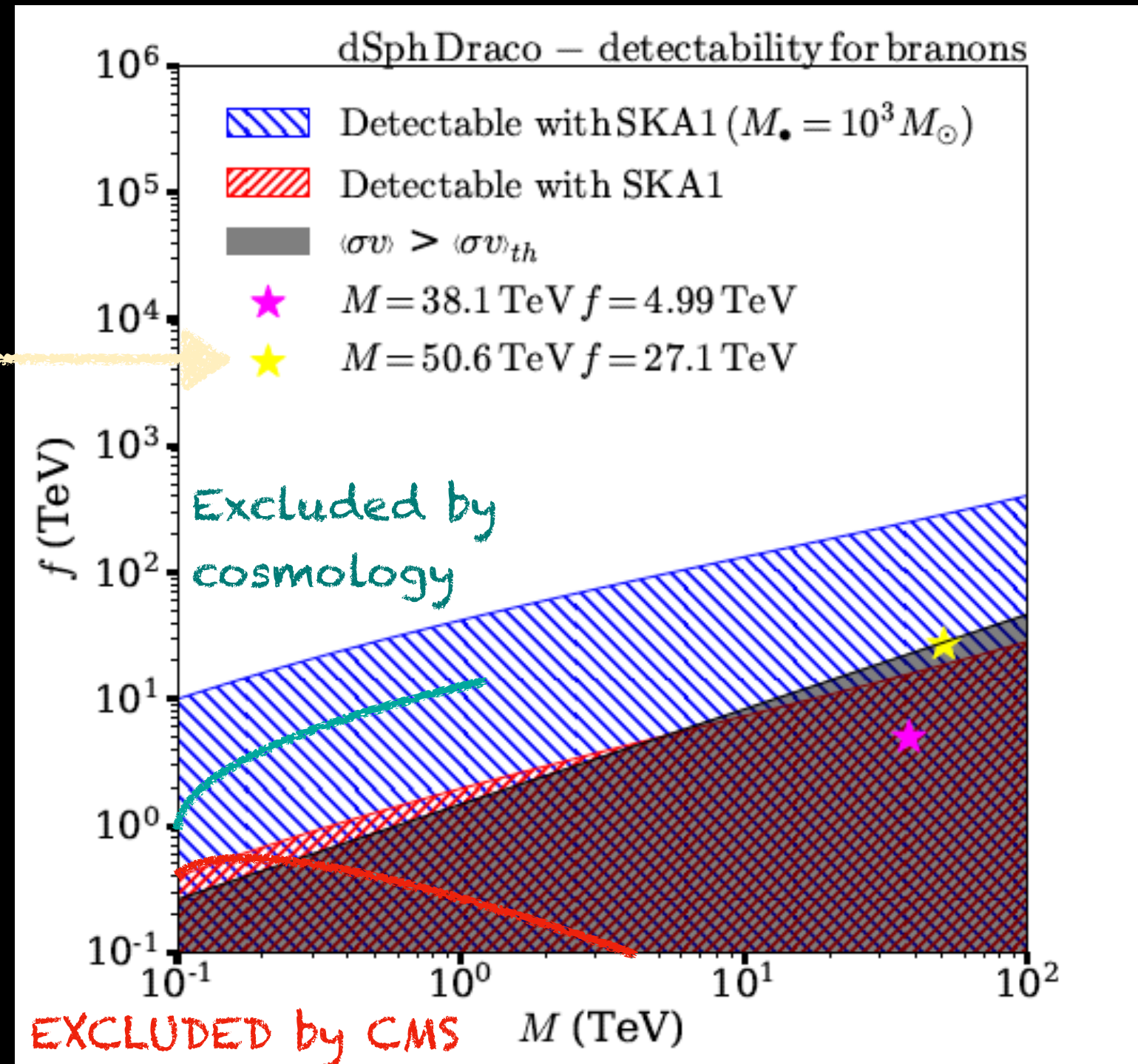
T. Miener, V. G., D. Nieto Castaño, in preparation



A. Aguirre-Santaella, V. G., D. Nieto Castaño,
M. A. Sánchez-Conde, in preparation



Branons @ Draco dSph with SKA



GC Multi-TeV
branon candidate

J.A.R. Cembranos, A.
Dobado, A.L. Maroto,
Phys.Rev.D68:103505,2003

CMS
Collaboration

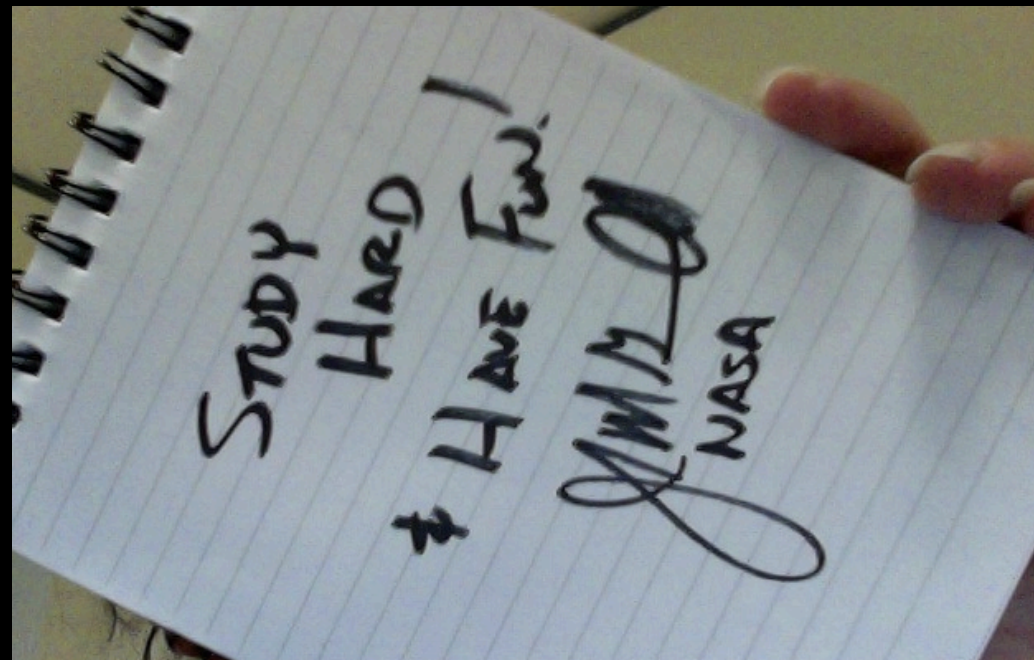
Physics Letters B
Volume 755, 10
April 2016, Pages
102-124

J. A. R. Cembranos, A. de la Cruz-Dombriz, V. G. , M. Mendez-Isla arXiv:1905.11154, submitted

Conclusions

- I hope I have convinced you that searching indirect signatures from multi-TeV DM candidate is a worth effort and represents the next frontier in the era of TeV observatories.
- Branon represents one prospective multi-TeV DM candidate. The study of particle physics nature of multi-TeV DM candidate at colliders is a challenge and represents a new frontier in physics.
- By analysing data of the current (e.g. MAGIC and HAWC) and next generation (e.g. SKA and Cherenkov Telescope Array (CTA)) of observatories we will set further constrains on the branon multi-TeV DM candidate.
- Work in progress....

Thank you for your attention



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 @GammaldiV