Multi-TeV Dark Matter

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15th international conference on the

DARK SIDE OF THE UNIVERSE

15th of July 2019, Buenos Aires, Argentina.

Outlook

- Multi-TeV Dark Matter (DM): motivation & previous works
- TeV DM candidates
- Multi-wavelength prospects with the Square Kilometre Array (SKA)
- TeV DM searches in dwarf irregular galaxies with the High Altitude Water Cherenkov (HAWC) Observatory
- Conclusions

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Dark Matter searches

DM Model and spin dependent
GeV<m_{DM}<TeV

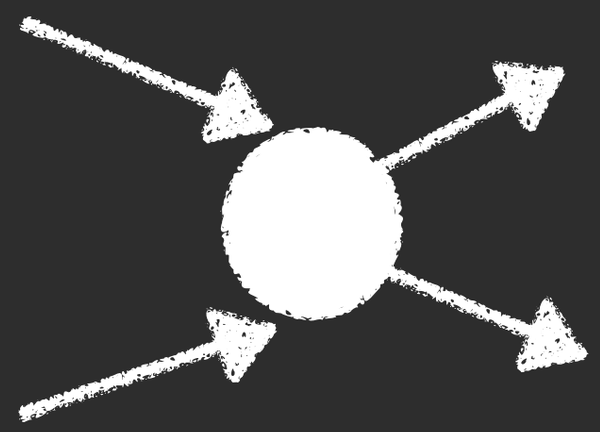
Indirect detection

DM Model Independent and
MeV<m_{DM}< PeV

Direct detection
(Underground experiments)

DM

χ Particles



SM

(quarks, bosons, leptons)

DM

Energy $\equiv$ χ Mass

SM

Channel $\equiv$ χModel

DM Model dependent and
GeV<m_{DM}<TeV

Detection at Colliders (CERN, LHC etc..)

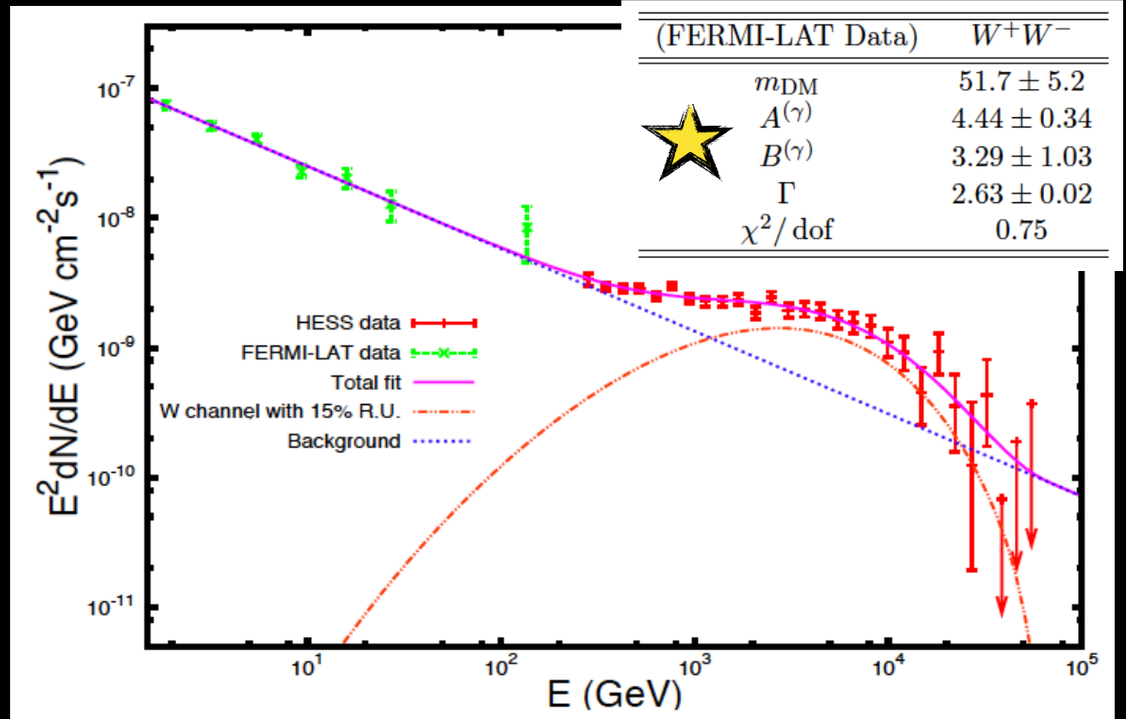
Motivation

- 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…)

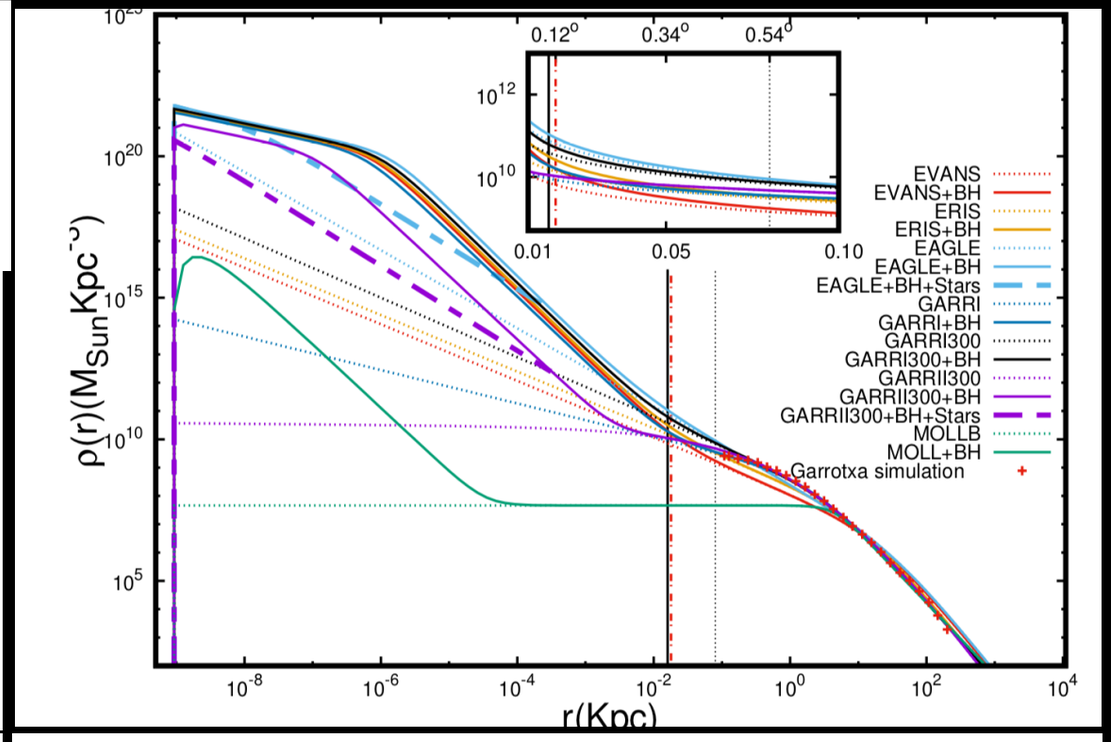
No conclusive evidence for DM so far.

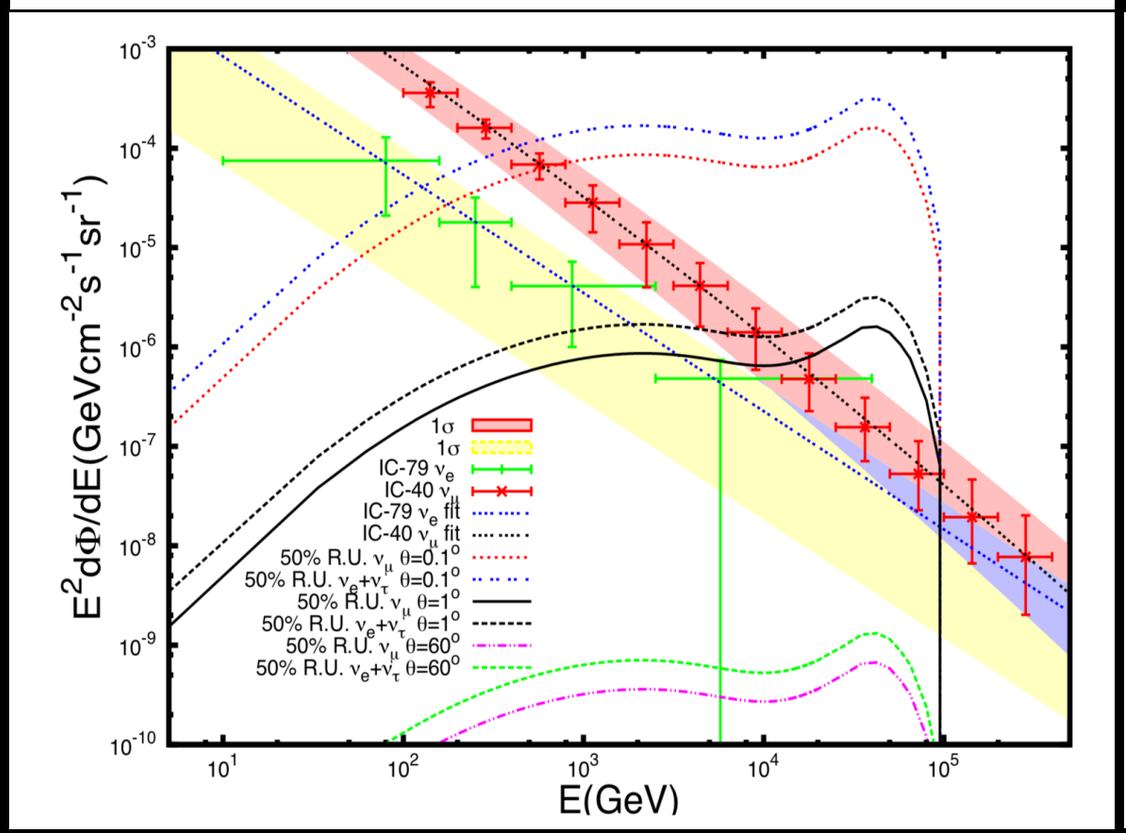
Previous works I

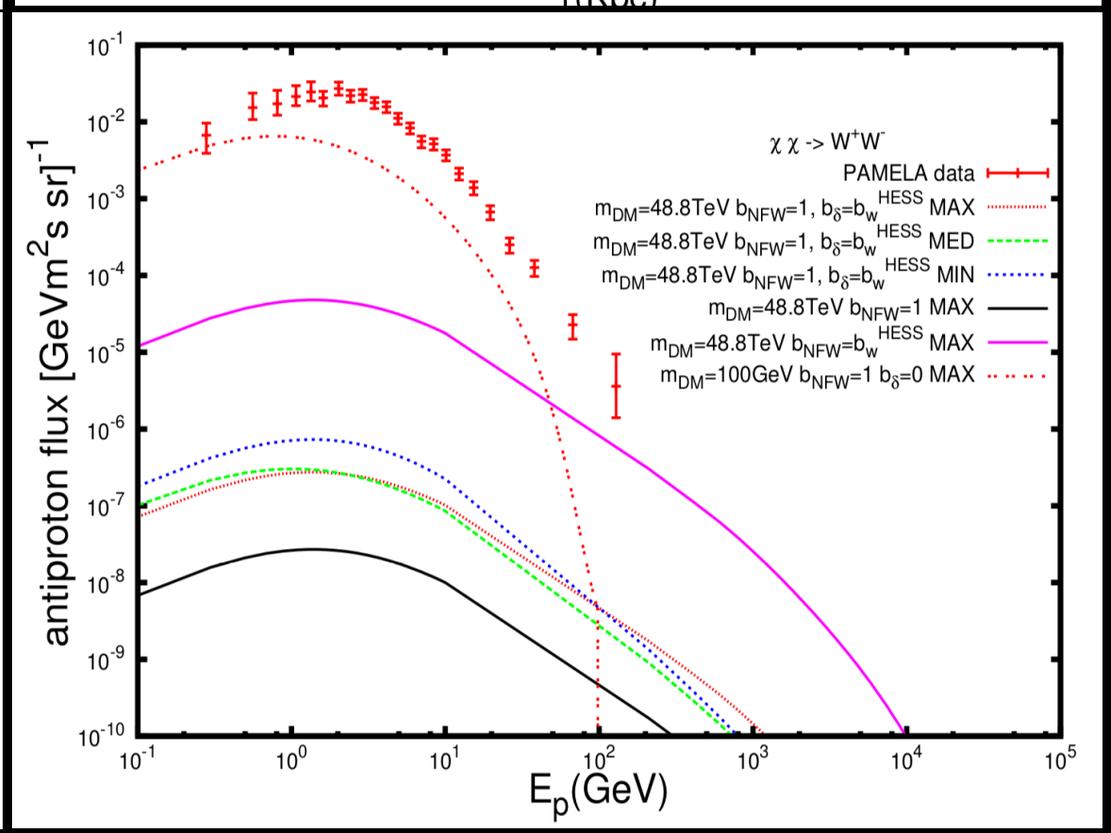
V.G. , Front. Astron. Space Sci., 05 April 2019



(FERMI-LAT Data)	W^+W^-
$m_{\rm DM}$	51.7 ± 5.2
$A^{(\gamma)}$	4.44 ± 0.34
$B^{(\gamma)}$	3.29 ± 1.03
Γ	2.63 ± 0.02
$\chi^2/\,\mathrm{dof}$	0.75







Previous works I

- 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 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

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

$$\alpha = 1 \ldots N$$

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

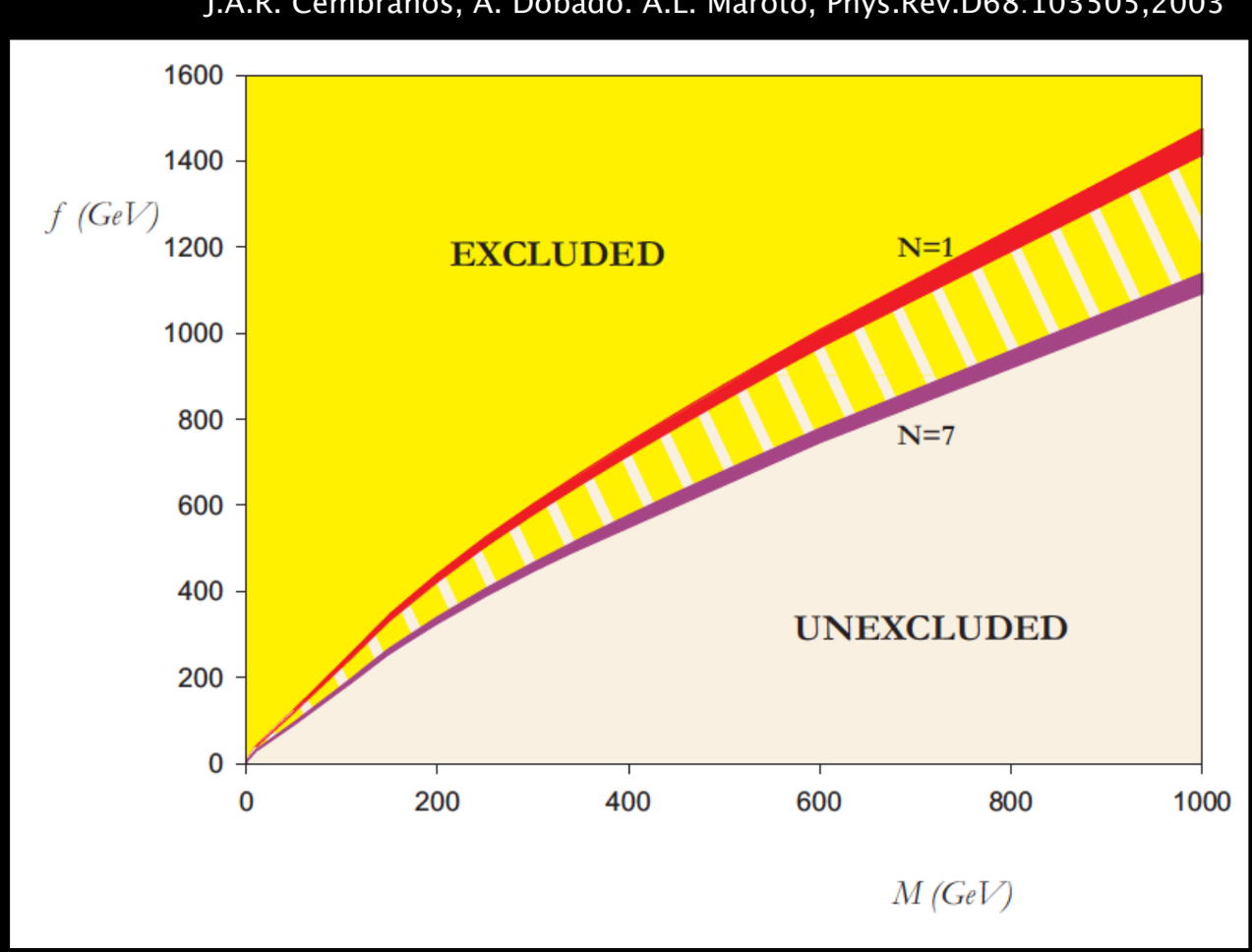
-> massive particles

✓ Their couplings are suppressed by the tension f^4

-> weakly interacting

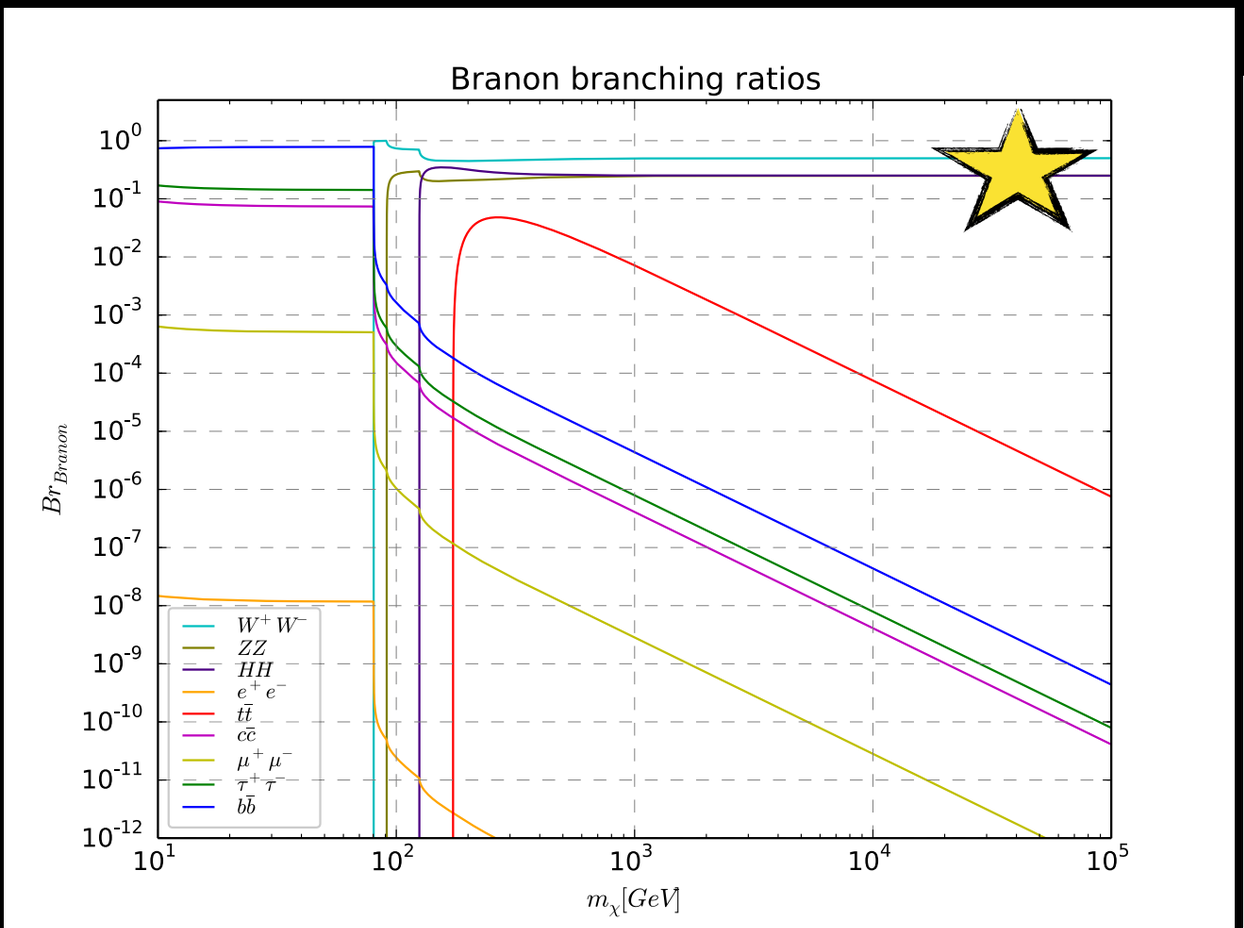
Natural WIMP candidate

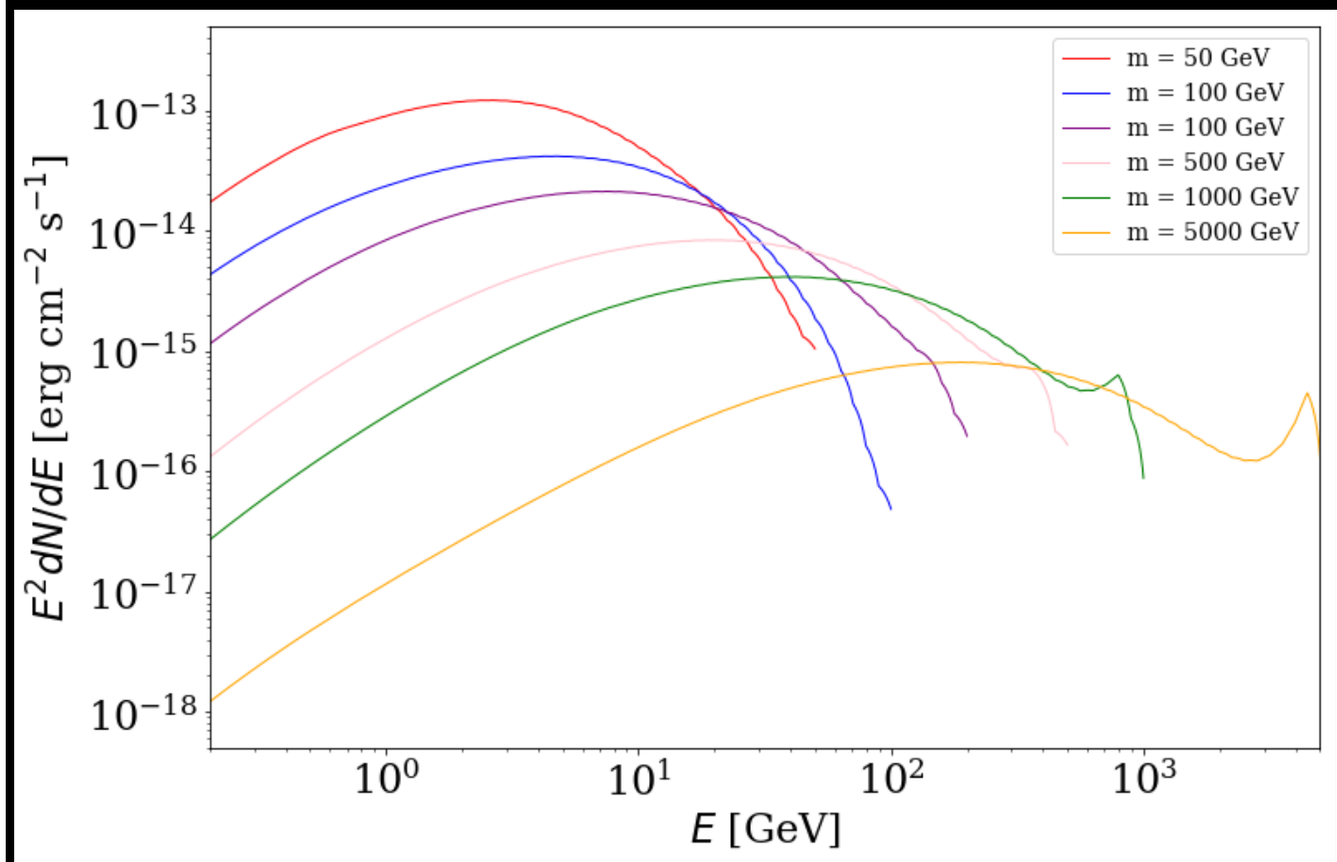
J.A.R. Cembranos, A. Dobado. A.L. Maroto, Phys.Rev.D68:103505,2003



The branon DM candidate

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





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

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Multi-wavelength TeV DM

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:

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

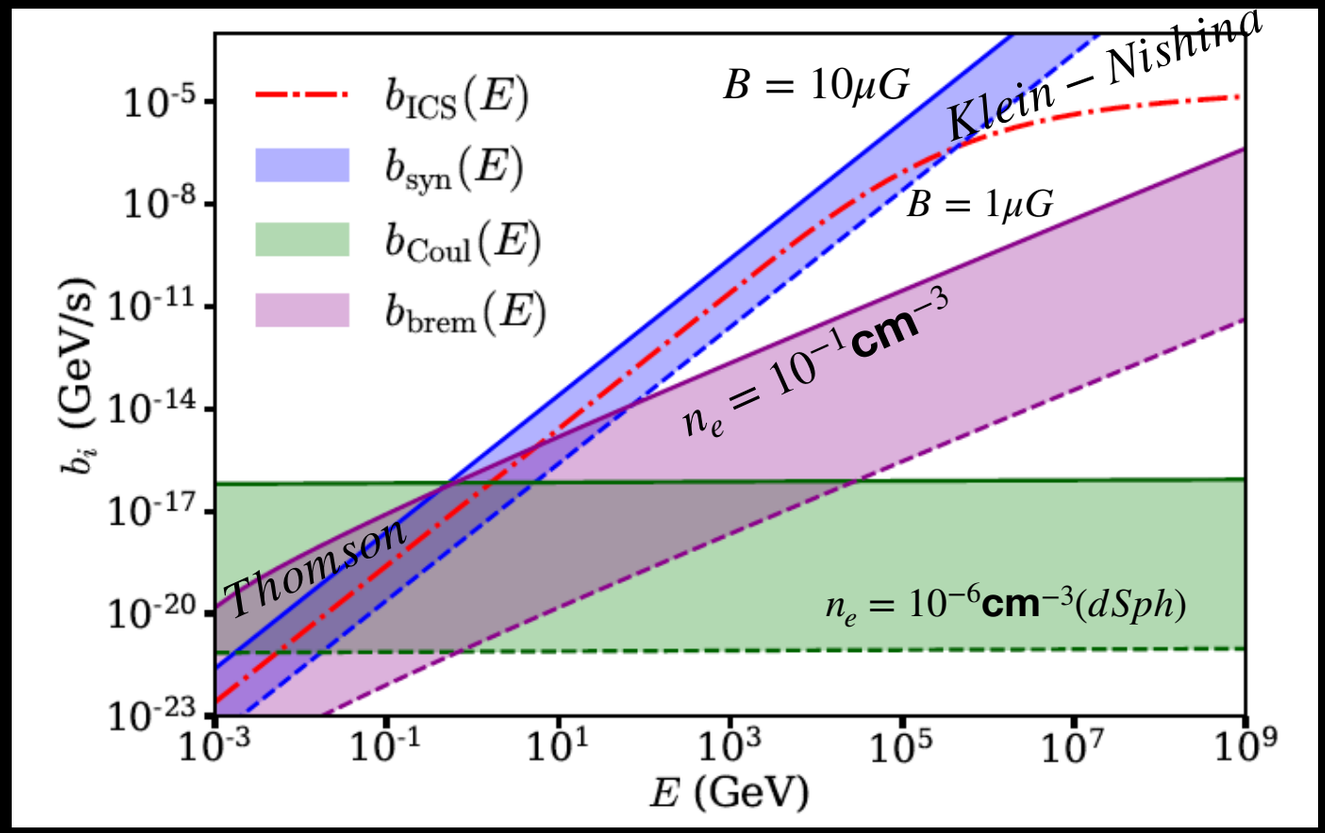
Number density after propagation

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

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

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

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



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

Multi-wavelength TeV DM @ Draco dSph with SKA

Emissivity

$$\psi(\mathbf{r},E)=\frac{1}{b(\mathbf{r},E)}\int_E^M \mathrm{d}E_s\, G\left(r,E,E_s\right) Q_e(\mathbf{r},E) \quad \rightarrow \quad \boxed{j_\nu(\mathbf{r},z)=\int_E^M \mathrm{d}E\left(\psi_{e^+}+\psi_{e^-}\right) P_{\mathrm{syn}}(\nu,\mathbf{r},E,z) 2\int_E^M \mathrm{d}E\,\psi(\mathbf{r},E) P_{\mathrm{syn}}(\nu,\mathbf{r},E,z)}$$

Green's function

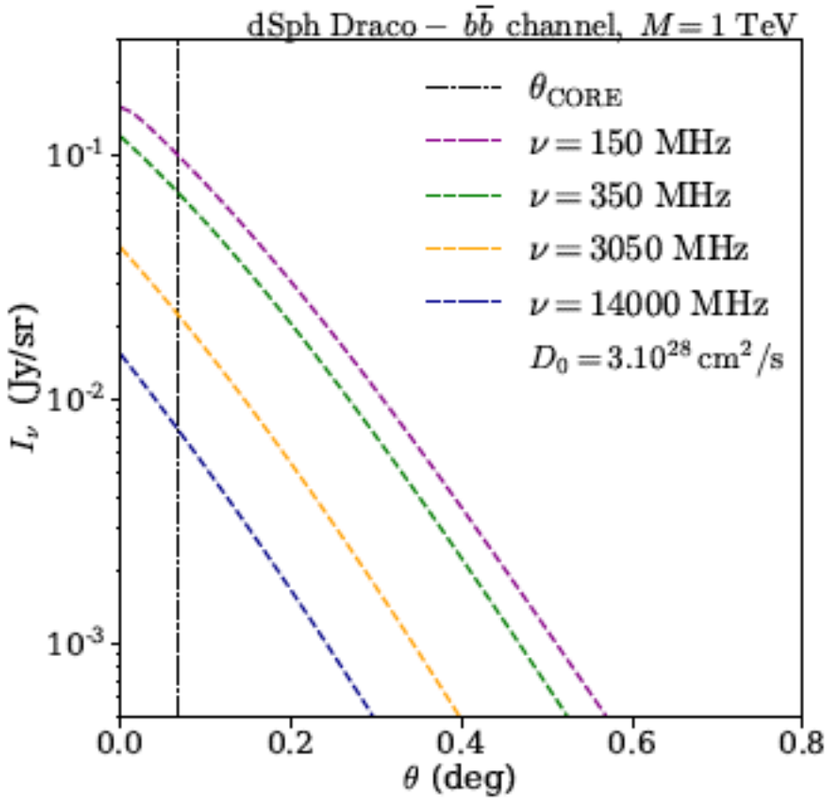
Power of emission: $P_{\mathrm{syn}}(\nu,\mathbf{r},E,z)=\int_0^\pi \mathrm{d}\alpha \frac{\sin^2\alpha}{4\pi\epsilon_0}\frac{\sqrt{3}e^3B(\mathbf{r})}{m_e c}F_i\left(\frac{\nu(1+z)}{\nu_c(\mathbf{r},E)\sin\alpha}\right)$

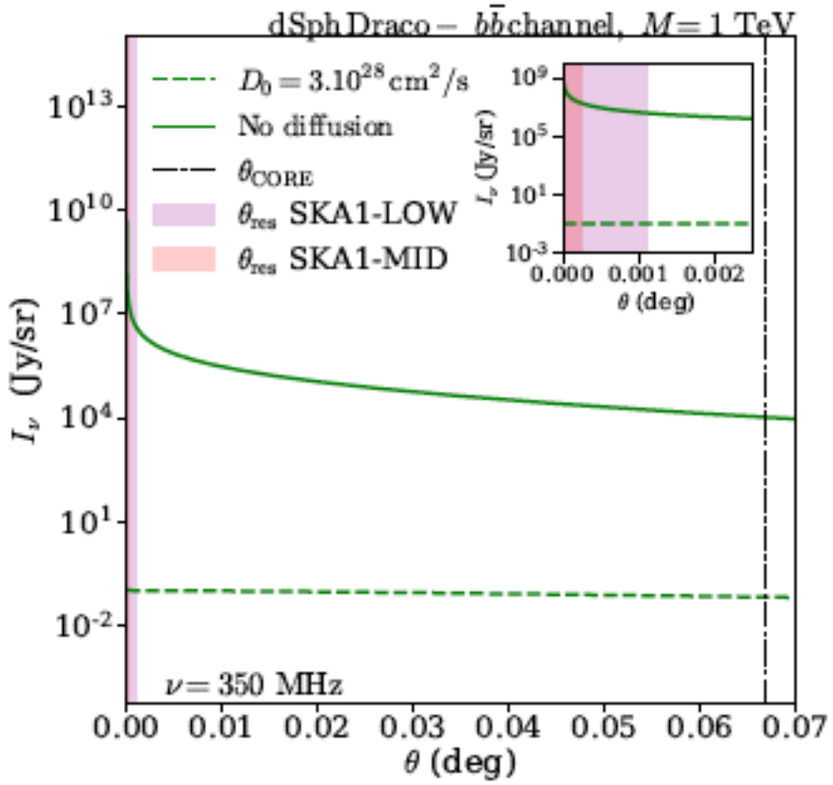
Source term: $Q_e(\mathbf{r},E)=\frac{1}{2}\langle\sigma v\rangle\left(\frac{\rho_{\mathrm{DM}}(\mathbf{r})}{M}\right)^2\sum_j \beta_j\frac{\mathrm{d}N_e^j}{\mathrm{d}E}$

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

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

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





Specific Intensity

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

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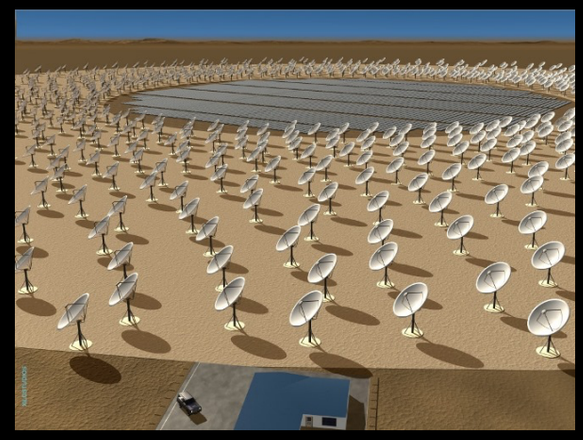
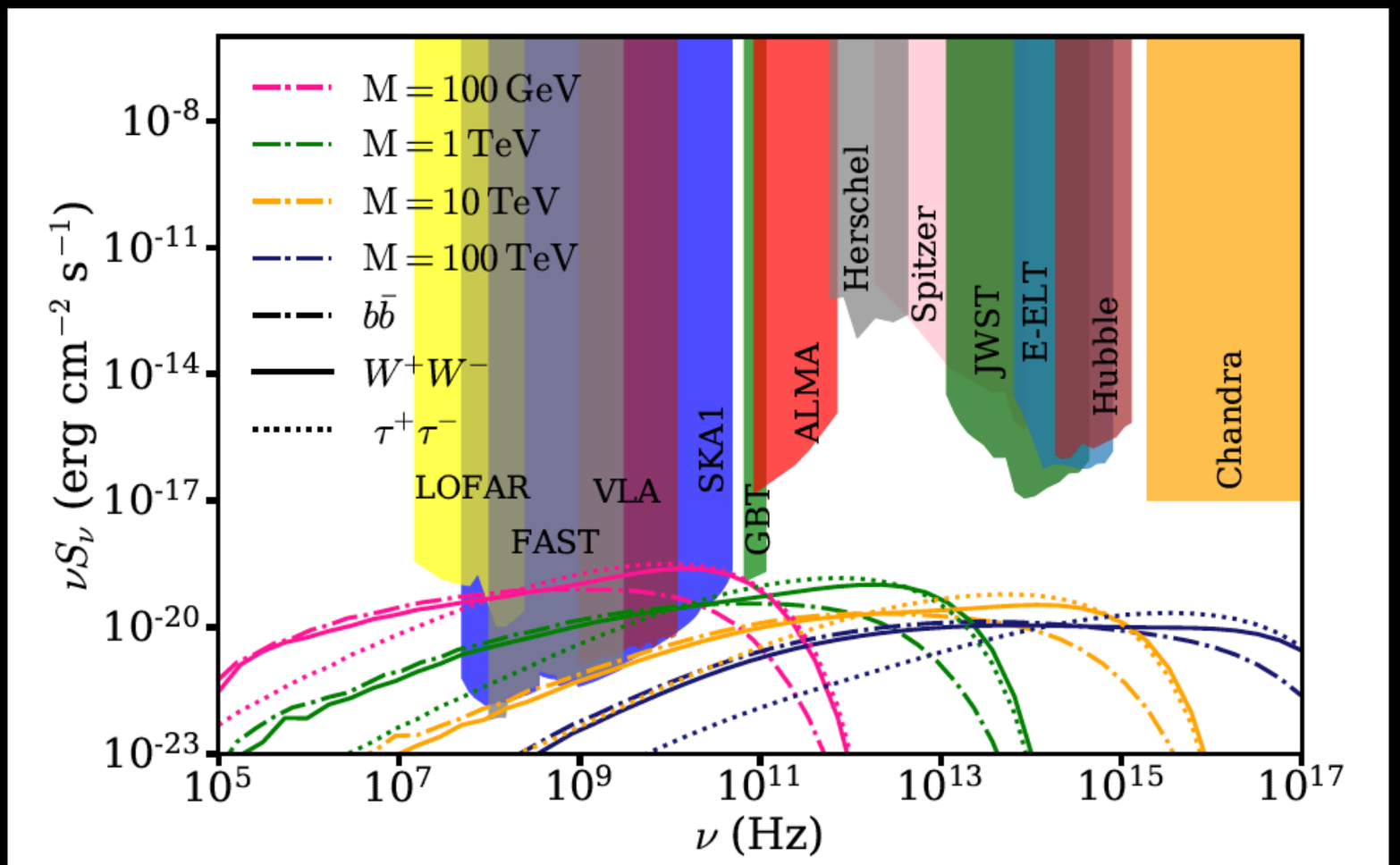
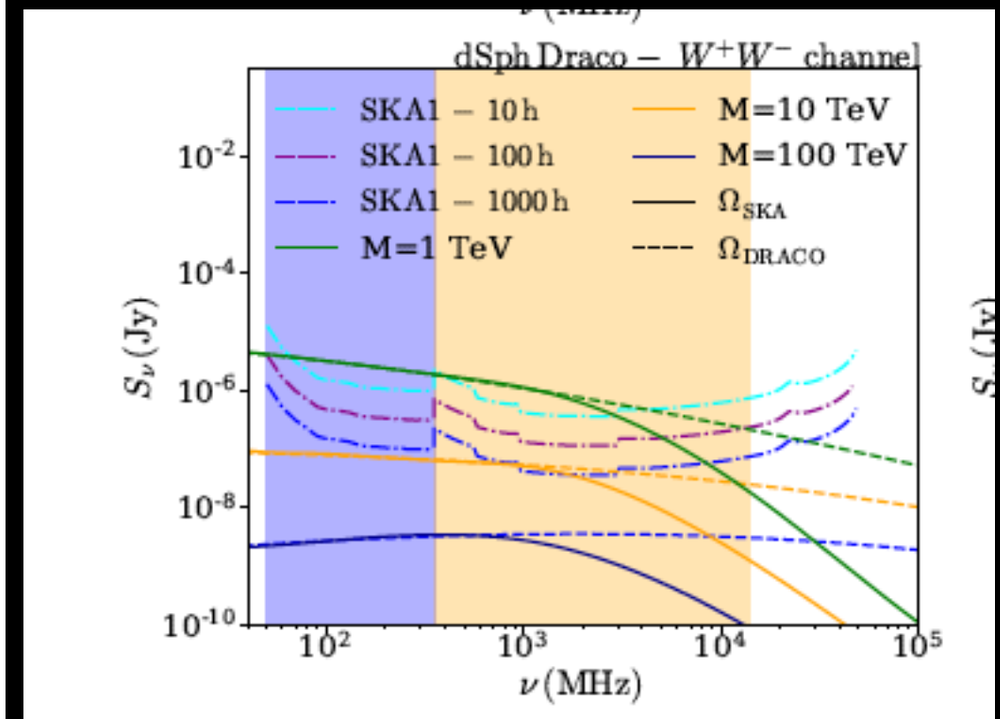
Multi-wavelength TeV DM @ Draco dSph with SKA

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







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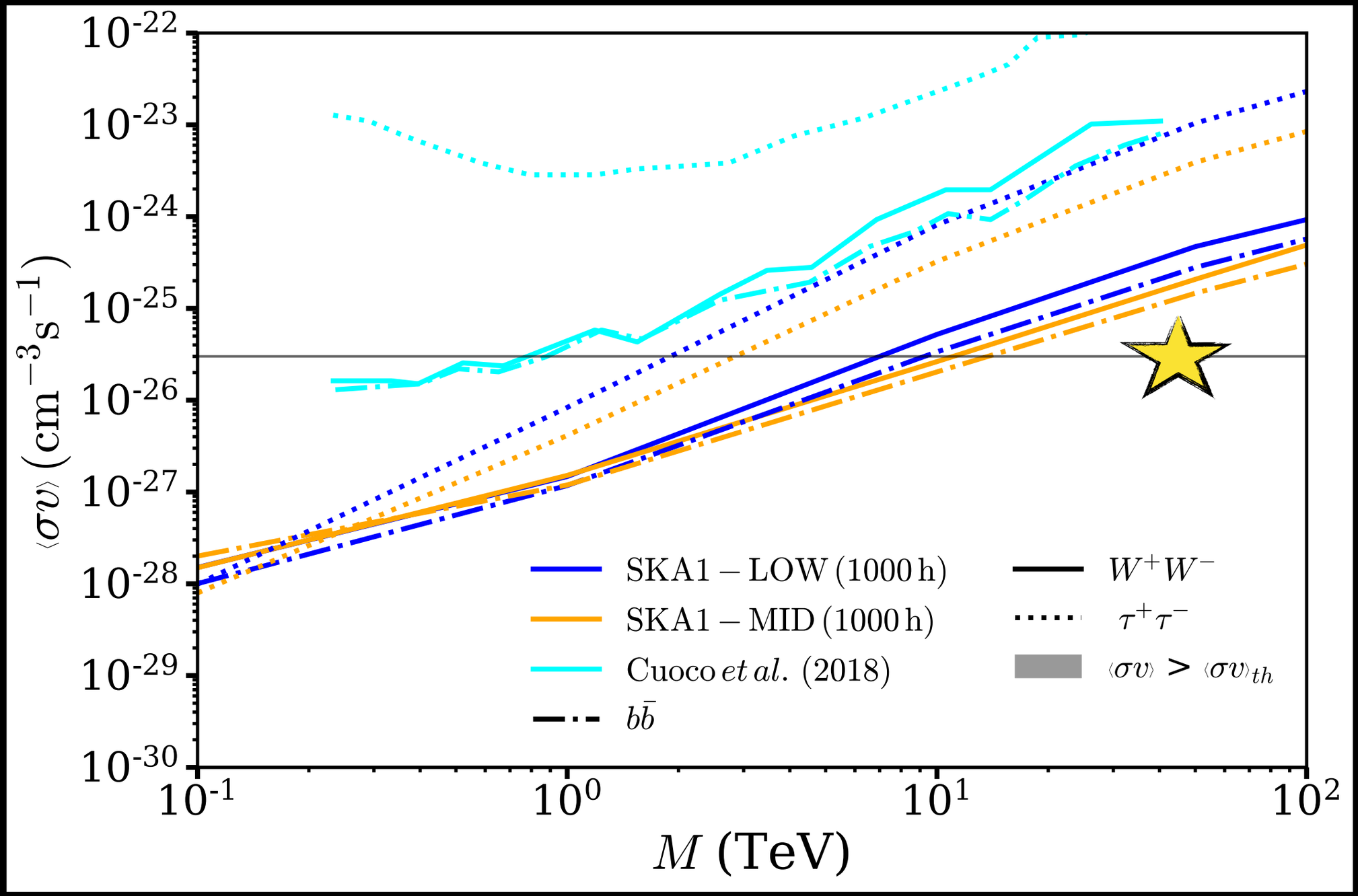
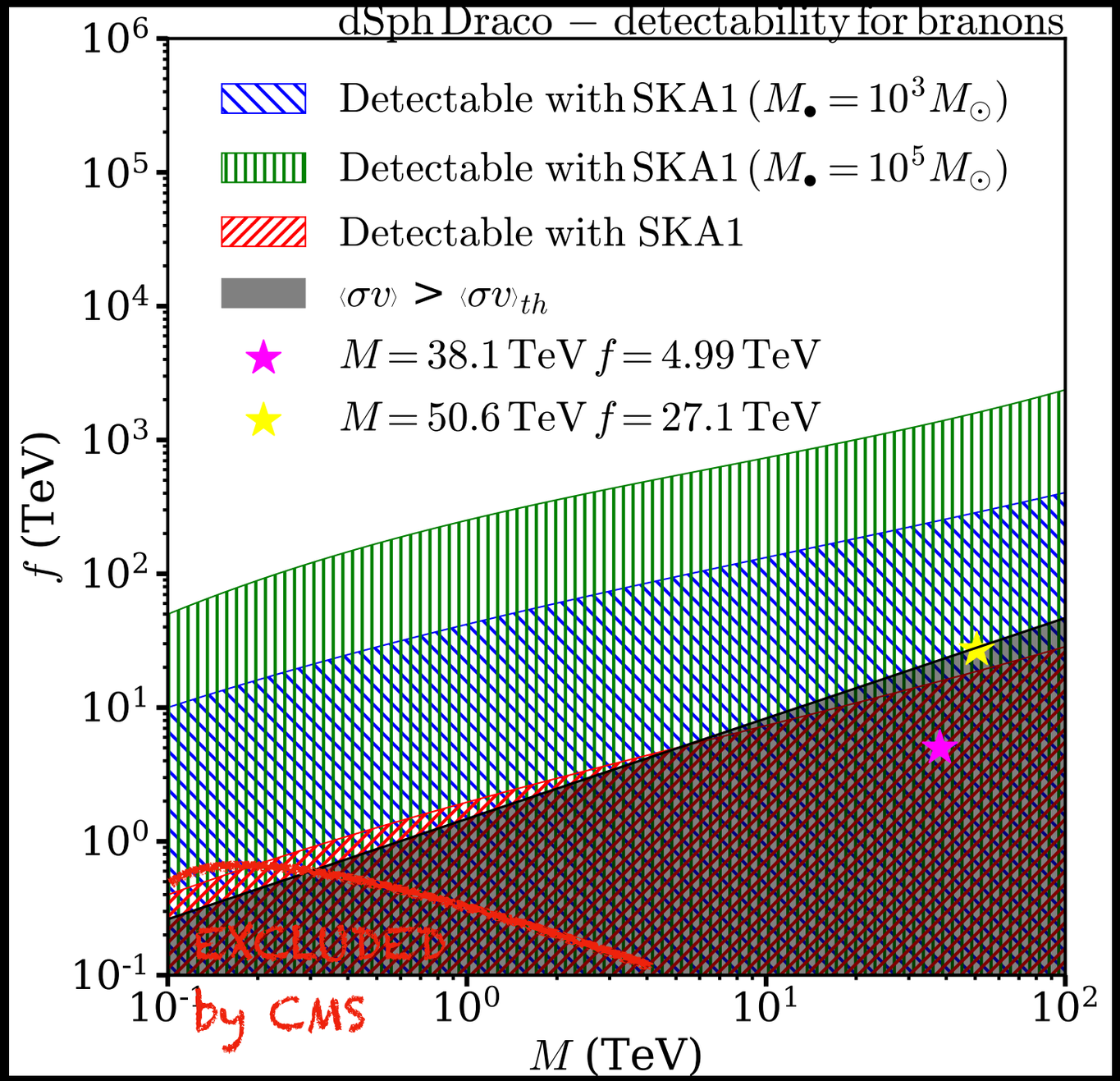
Multi-wavelength TeV DM @ Draco dSph with SKA



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

branon TeV DM candidate @ Draco dSph with SKA



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
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TeV DM @ dwarf irregular galaxies

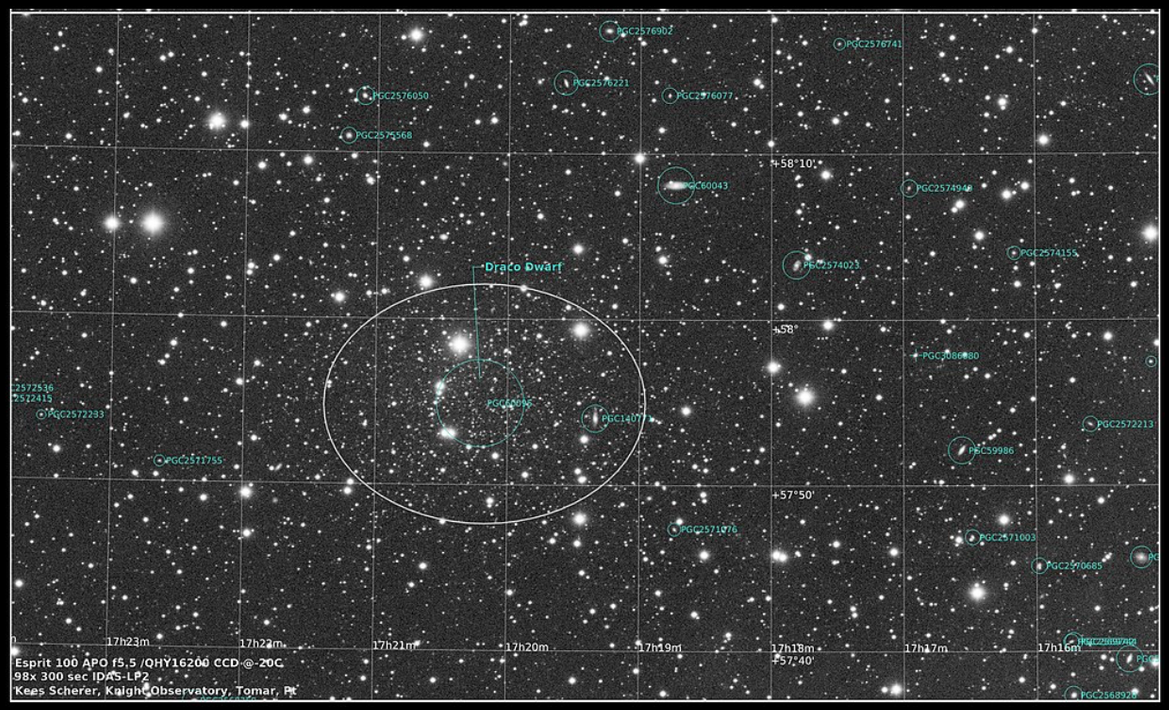
Dwarf spheroidal (dSph) galaxies

The Draco Spheroidal Dwarf Galaxy

Dwarf irregular (dIrr) galaxies

TeV DM @ dwarf irregular galaxies

Dwarf spheroidal (dSph) galaxies



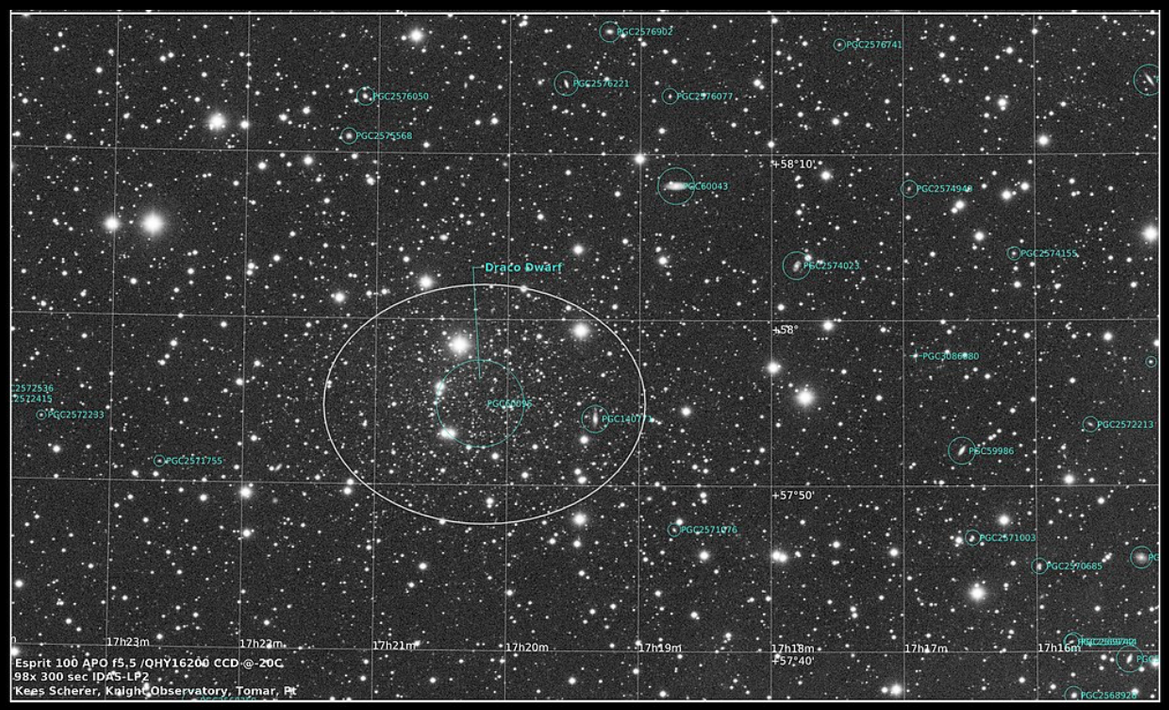
The Draco Spheroidal Dwarf Galaxy

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



The Draco Spheroidal Dwarf Galaxy

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

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_{halo} 10^6-10^8

10^{14} (Segue 2) < J-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 Mpc <d< 10 Mpc

Rotationally supported objects
(rotation curve)

DM dominated objects M_{halo} 10^8-10^{10}

10^{14} < J-factors < 10^{18}

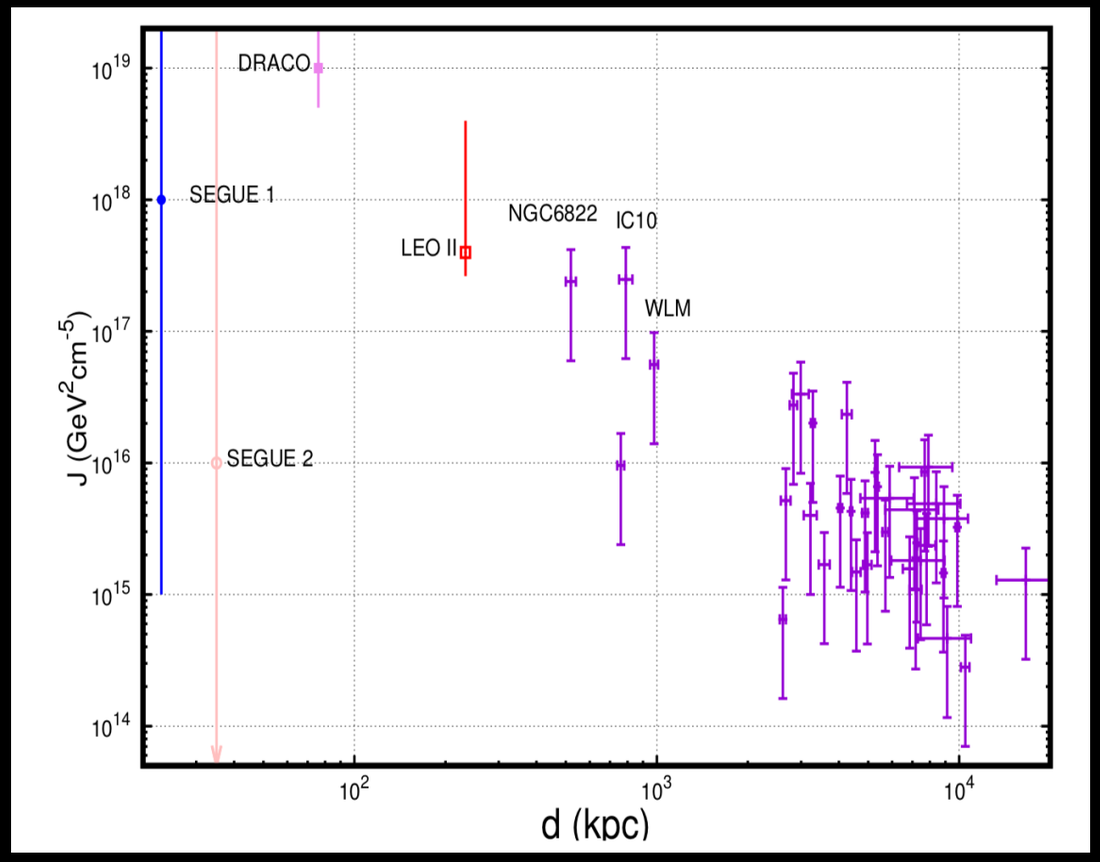
Previous work: **Star forming region**
and negligible astrophysical background
in gamma-rays? Yes!

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

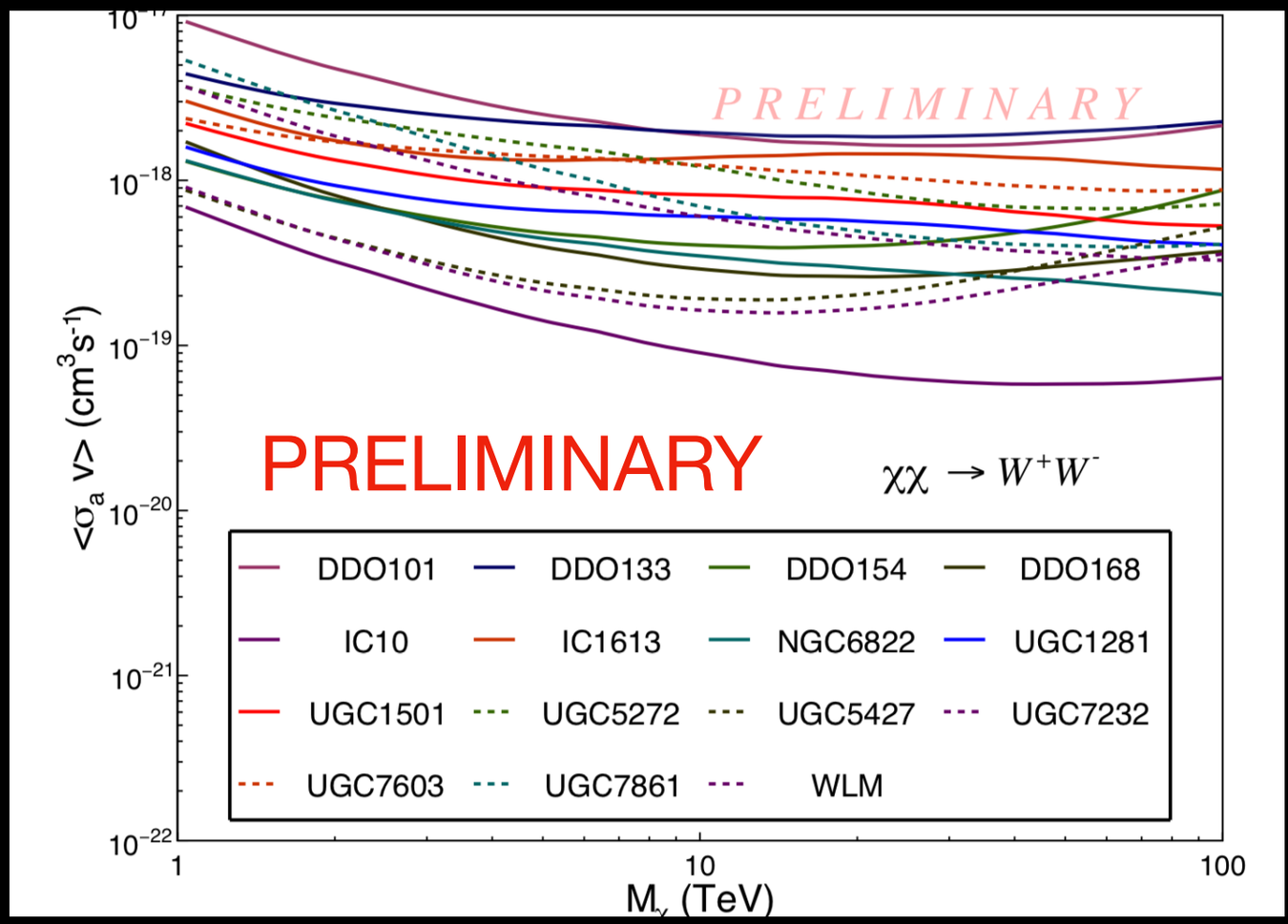
never analyzed
in the context of gamma-ray DM searches

TeV DM with HAWC @ dwarf irregular galaxies

- HAWC Observatory (Mexico) with large sky coverage
- No gamma-ray signal detected from dIrrs
- Point-like analysis for dSphs 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)

Conclusions

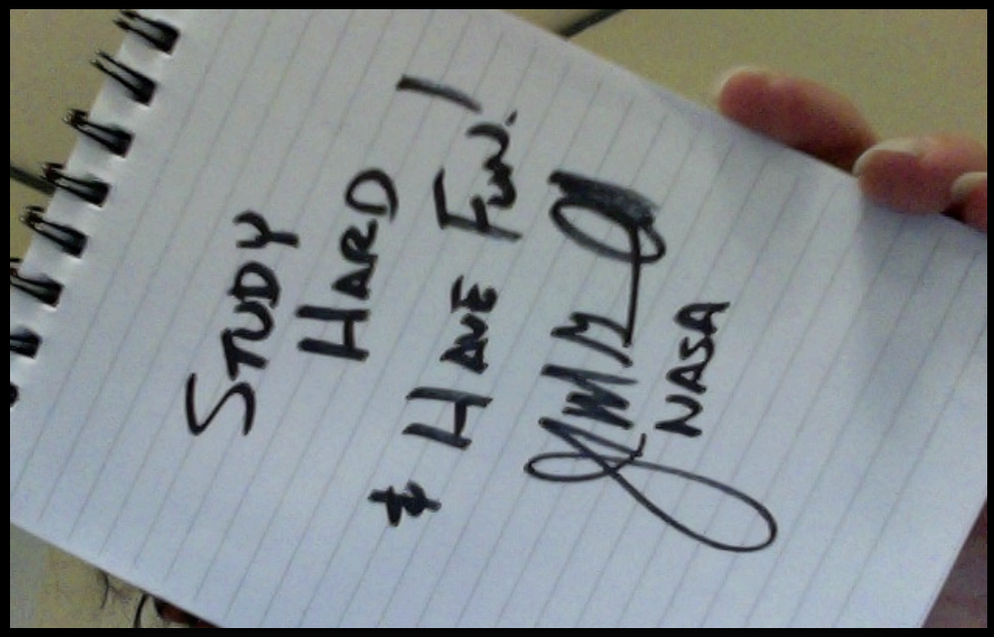
- I hope I have convinced you that searching indirect signatures from multi-TeV DM candidate is a worth effort and represents the next frontier in the era of TeV observatories.

- 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.

- Current available data (from e.g. MAGIC and HAWC) and next observatories (e.g. SKA and Cherenkov Telescope Array (CTA)) will be fundamental in order to set further constrains on the multi-TeV DM candidate.

- Work in progress….

thank you for your attention



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