Constraining Secluded Dark Matter Scenarios with HAWC

Sergio Hernández
skerzot@gmail.com
For the HAWC Collaboration

Dark matter searches in the 2020s
At the crossroads of the WIMP
University of Tokyo, Kashiwa Campus, Japan

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Hidden Sector

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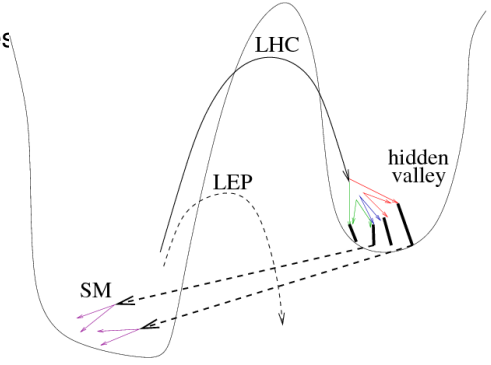
   - Sizes and numbers of small dark haloes
   - Core-cusp problem
5. Model Dependent Search
6. Model Independent Search



Morrissey, D.E. et al 2012

A quick glance at the thermal history

- Dark plasma is in equilibrium with SM plasma
- DM freeze-out ($\sim m_{\chi_{\rm HS}}/30$)
- Bound State Formation (BSF) dominates over annihilation process
- Decay of bound states dominates over ionization. DM kinematically decouples from dark photons
- Posterior decay of dark photons
- See Cirelli *et. al.*, JCAP05, 2017 and Harling *et. al.*, JCAP12, 2014

DM searches

1. $U(1)$-like dark interaction ($U_D(1)$) via a dark photon
2. Coupling to SM particles via kinetic mixing of $U_D(1)$ with $U(1)$ (possible Dark Portals)
3. Cascade Annihilation:

$$\chi_{HS}\chi_{HS} \to \phi_n\phi_n \to 2 \times \phi_{n-1}\phi_{n-1} \to \cdots 2^{n-1} \times \phi_1\phi_1 \longrightarrow 2^n \times \mathrm{SM}_f\mathrm{SM}_f$$

4. The level of final state radiation and hadronization of SM_f states is mediated by a $\epsilon_f = \sum m_{\mathrm{SM}} m_{\phi_1}^{-1}$
5. Strict lower bound on the DM mass (n is the number of cascade steps):

$$m_\chi \geqslant 2^n \frac{\epsilon_f}{m_f}$$

See Elor *et. al.*, JCAP06, 2016

Massless Dark Photon

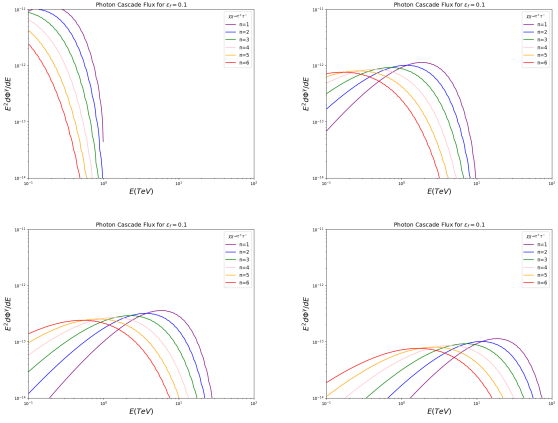
1. Long $U_D(1)$ interaction carried by a massless photon
2. Production of positronium-like bound states of $\chi_{HS}\chi_{HS}$ with radiation of dark photons and posterior decay to SM particles
3. Thermal-average cross-sections depend on the BSF-Rate, temperature of DM plasma, relative velocity of DM particles, and α_D.
4. Use data of current gamma-ray observatories to constrain the value of parameters

$$\text{Data} \rightarrow \Phi_\gamma^{(\text{U.L.},95\%)} \rightarrow \langle \sigma_{\chi_{\text{HS}}} v \rangle^{(\text{U.L.},95\%)} = \langle \sigma_{\chi_{\text{HS}}} v \rangle^{(\text{U.L.},95\%)}(\alpha_D, v, ...)$$

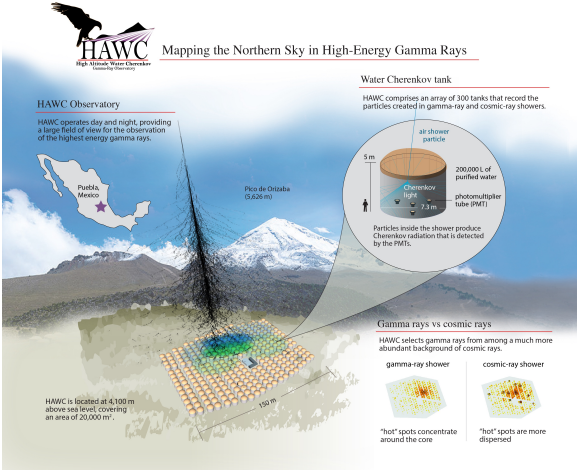
5. Constraints for α_D (vs DM mass)

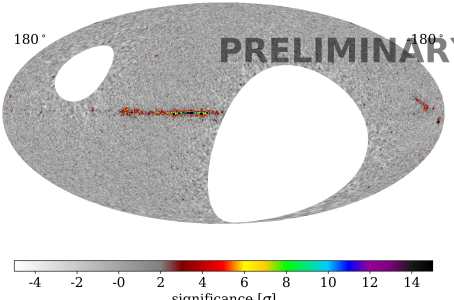
Multi-step Annihilations

- † Spectrum taken from PPPC4DMID
- † Constraints on the $\langle \sigma_\chi v \rangle - m_\chi$ space
- † Spectra does not change with respect to the nature of the Dark photon
- † Try to cover the majority of parameter space for dark sectors
- † Increasing the number of steps, the spectrum moves to lower energies



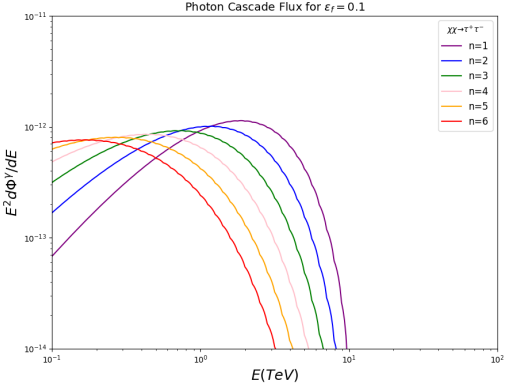
The HAWC Observatory



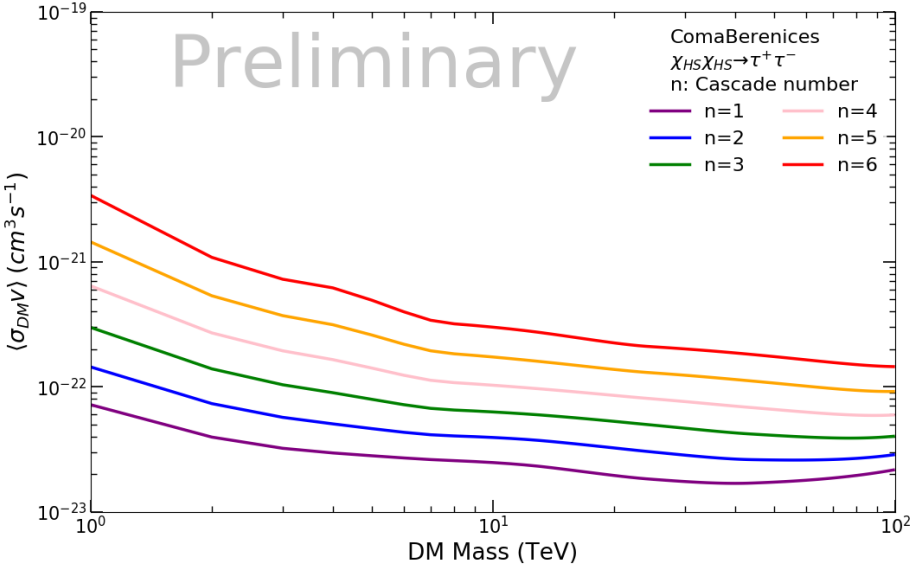


Analysis for the Coma Berenices Galaxy

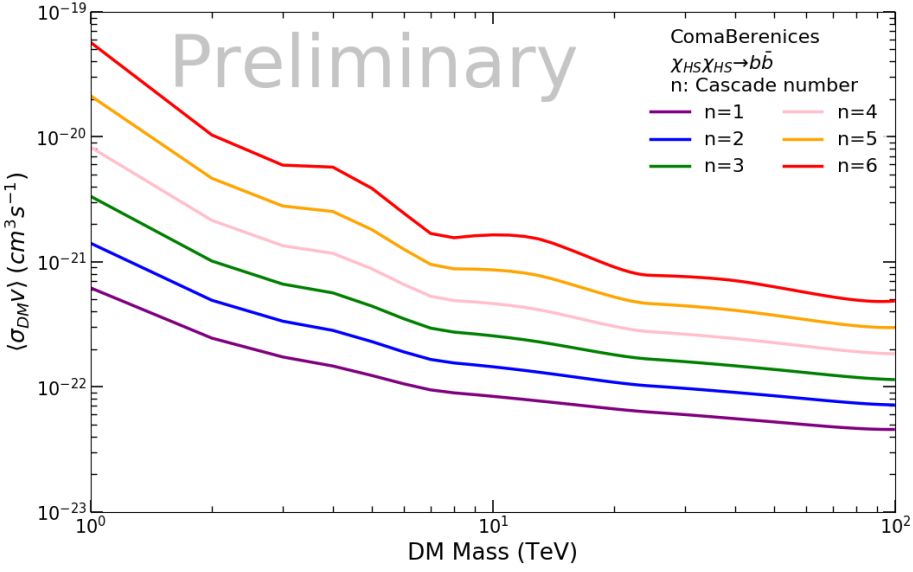
- Coma Berenices: $(186.74°, 23.90°)$
- J factor: $2.089 \times 10^{13}\text{TeV}^2\text{cm}^{-5}$
- Annihilation channels: $\chi_{HS}\chi_{HS} \rightarrow \{\tau^+\tau^-, \mu^+\mu^{-1}, W^+W^-, b\bar{b}\}$
- HAWC data $\sim$ 1300 transits
- No statistical significance excess observed
- Exclusion Limits at 95% C.L.



Model Independent Limits: $\tau^+\tau^-$-channel



Model Independent Limits: $b\bar{b}$ channel



Summary

- Particles within a hidden sector are suitable DM candidates
  - Freeze-out and DM relic density
- Gamma-Ray data must be used to constrain properties of the dark interaction
- Model-independent searches:
  - Variations in the spectrum with few parameters
  - Multi-step annihilation of DM
- HAWC constraints are the most restrictive for masses above 10 TeV

Thanks for your attention
ご清聴ありがとうございました