Constraining dark matter scenarios with gamma-ray box-shaped features

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Outline

Dark matter and indirect detection

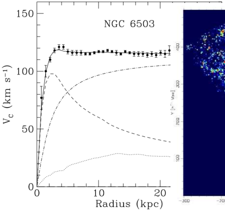
The box-shaped spectrum

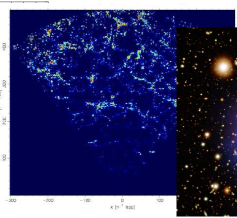
Concrete models

Conclusions

Evidence for dark matter

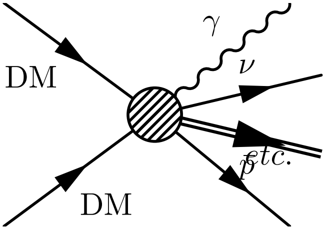
- There is an overwhelmingly amount of evidences for the existence of dark matter (**DM**).

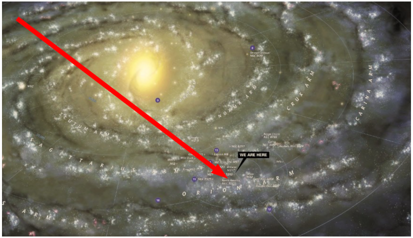




- The job we have is to find out what its (mysterious) nature is.

Indirect detection





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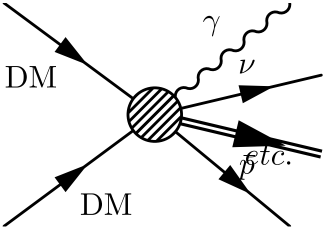
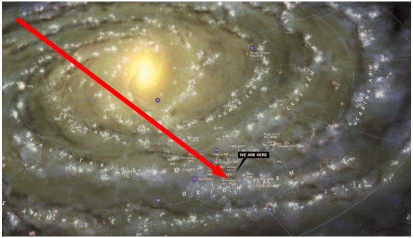
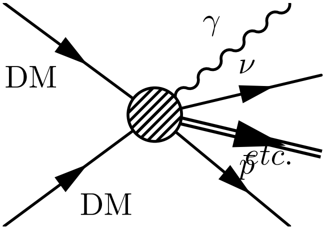
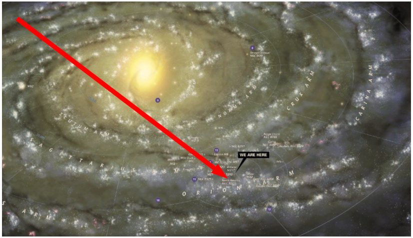




- Compute the expected flux of SM particles on earth
  - Antiprotons, Antideuterons...
  - Neutrinos
  - Gamma-rays

Indirect detection





- Compute the expected flux of SM particles on earth
  - Antiprotons, Antideuterons...
  - Neutrinos
  - Gamma-rays
- Compare with the expected background and look for excesses

Identify Dark Matter signals through gamma-ray observations:

Indirect detection

Gamma rays

Identify Dark Matter signals through gamma-ray observations:

- Smooth gamma-ray spectrum
  - Final-state radiation from charged particles ($e^{\pm}$, $\mu^{\pm}$)
  - Pion decay
  - Inverse Compton scattering
- Spectral features are a very clean way to spot Dark Matter $\rightarrow$ smoking-guns

Indirect detection

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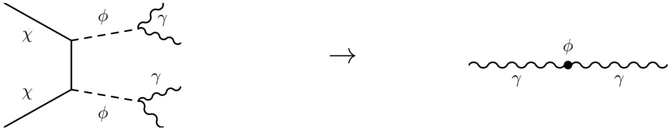
  Gamma-ray features:
  - Gamma-ray lines
  - Internal bremsstrahlung
  - Gamma-ray "boxes" (this talk)

Box-shaped spectrum

A. Ibarra, SLG, M. Pato (arXiv:1205.0007 [hep-ph])

- Consider the annihilation:

$$\chi\chi \to \phi\phi \Longrightarrow \phi \to \gamma\gamma$$



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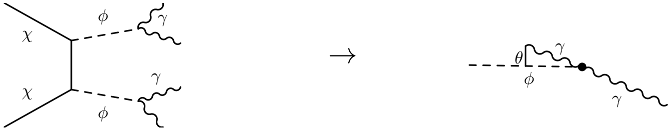

- Energy of the photons in the rest frame of ϕ: $E_\gamma^{\mathrm{RF}} = m_\phi/2$
- Momentum of the intermediate scalar $p_\phi = \sqrt{m_\chi^2 - m_\phi^2}$
- Energy of the photons in the lab frame

$$E_\gamma^{\mathrm{Lab}} = \frac{m_\phi^2}{2\,m_\chi}\left(1 - \cos\theta\sqrt{1 - \frac{m_\phi^2}{m_\chi^2}}\right)^{-1}$$

- The spectrum is characterized by m_χ & $\Delta m = m_\chi - m_\phi$

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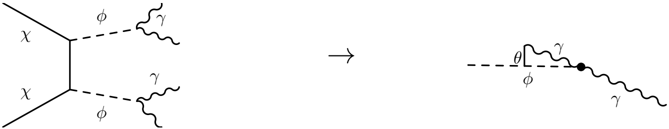

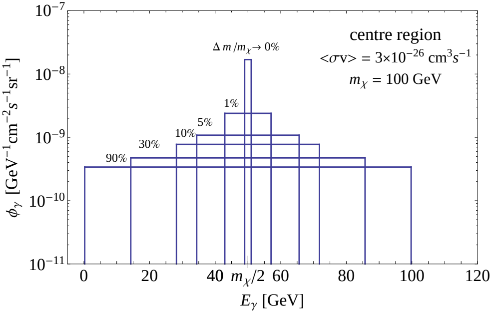

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- Flux

$$\phi_\gamma(E_\gamma) \equiv \frac{d^4 N_\gamma}{dE_\gamma dS d\Omega dt} = \underbrace{\frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE_\gamma}}_{\text{particle physics}} \underbrace{\frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \;\; J_{ann}}_{\text{astrophysics}} \quad ,$$

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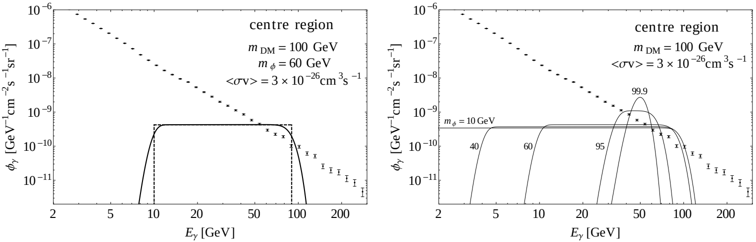

Data from G.Vertongen and C.Weniger (arXiv:1101.2610 [hep-ph])

- $\Delta m/m_\chi \to 0 \Longrightarrow$ monochromatic line with 4γ (narrow box)
- $\Delta m/m_\chi \to 1 \Longrightarrow$ dimmer but wider signal (wide box)
- $E_C = m_\chi/2$

Comparing models with experimental data

- The gamma-ray signal is characterized by the parameters

$$(m_\chi,\, \langle \sigma v \rangle_{\chi\chi\to\phi\phi},\, \Delta m)$$

- $BR(\phi \to \gamma\gamma)$ is model dependent
- We derive limits at 95% C.L. on the velocity-averaged cross section by comparing $\phi_\gamma + \phi_{\gamma,b}$ to the experimental data

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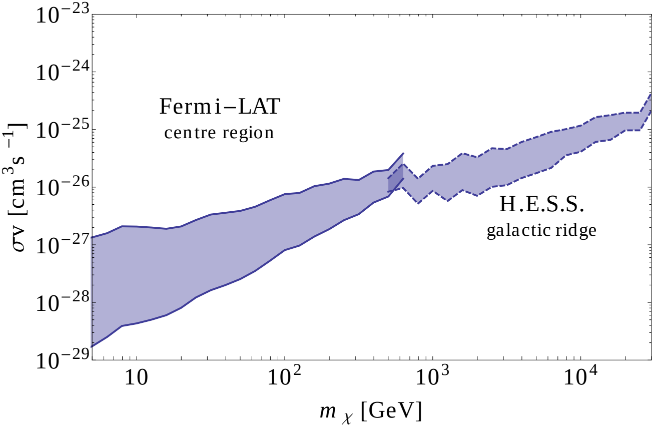
Two different approaches:

1. conservative $\to$ $\phi_{\gamma,\,b} = 0$
2. aggressive $\to$ $\phi_{\gamma,\,b} = data$

Constraints on a generic scenario



- $\mathrm{BR}(\phi \to \gamma\gamma) = 1$
- Narrow box scenario
- Majorana dark matter

Concrete model

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- A stable DM particle χ
- An intermediate scalar ϕ coupling to χ
- Sizeable BR of ϕ into photons

Concrete model

Y.Nomura and J.Thaler (arXiv:0810.5397)

- Motivated by the galactic positron excess

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Setup:

- A TeV-scale DM particle χ which annihilates into a pseudoscalar "axion" a and a scalar s
- Dominant decay of a into leptons, suppressed photonic decay mode
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- Such a scenario arises in any theory where m_χ is generated by the SSB of a global $U(1)_{\mathrm{X}}$. (Some models $U(1)_{\mathrm{PQ}}$)

Concrete model

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Physical parameters in this realization

$$m_\chi = 1\,\mathrm{TeV}$$

$$360\,\mathrm{MeV} \lesssim m_a \lesssim 800\,\mathrm{MeV}$$

$$\mathrm{BR}(a \to \gamma\gamma) \lesssim 1\%$$

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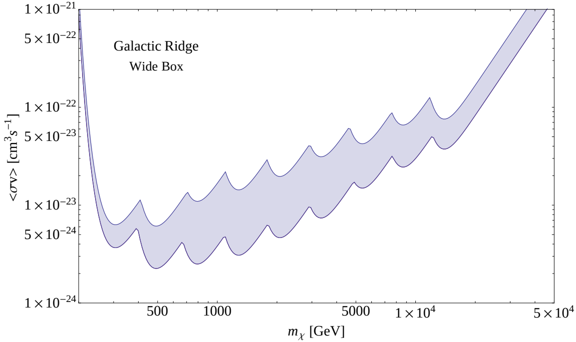
- Since $m_a \ll m_\chi$ we consider only a wide-box scenario
- The branching ratio into photons is small but still sizeable for our purposes
- The main annihilation channel is $\chi\,\chi \to s\,a$, i.e. only two photons per process
- Due to Sommerfeld enhancement and formation of DM bound states $\Rightarrow$ boost factor $\mathcal{O}(10^3)$

Constraints



- Since the model implies $m_a \ll m_\chi$ we consider only the wide-box scenario
- Since we are at TeV scales we use H.E.S.S. data of the galactic region ($|l| \leq 0.8^\circ \times |b| \leq 0.3^\circ$)
  H.E.S.S. col. (arXiv:astro-ph/0603021)

Another realization

H.M. Lee, M. Park, W.-I. Park (arXiv:1205.4675)
A. Ibarra, H.M. Lee, SLG, W.-I. Park, M. Pato (arXiv:1303.6632)

Introduce a $U(1)_{\rm PQ}$, a DM dirac fermion and a complex scalar field $S = (s + ia)/\sqrt{2}$, the complex part a serves as intermediate state coupling to photons via anomalies

- Consider a wide box scenario $m_a \approx 0.1 \times m_\chi$, and a narrow box scenario $m_a \approx m_\chi$
- BR($a \to \gamma\gamma$) depends on the mass of the pseudoscalar and takes different values between 0.05 and 1.

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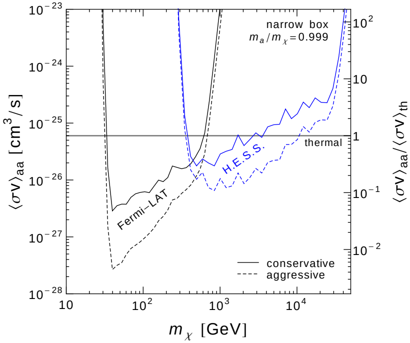
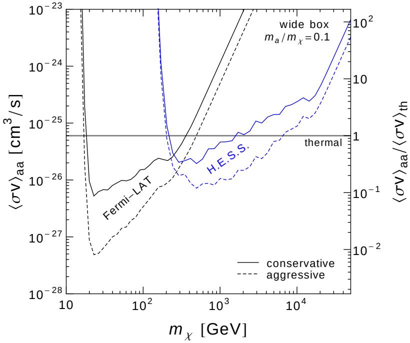




- We consider $\mathrm{BR}(a \to \gamma\gamma) = 1$
- Low energies Fermi-LAT data (Reg3 of arXiv:1204.2797)
  High energies H.E.S.S. data (arXiv:astro-ph/0603021)

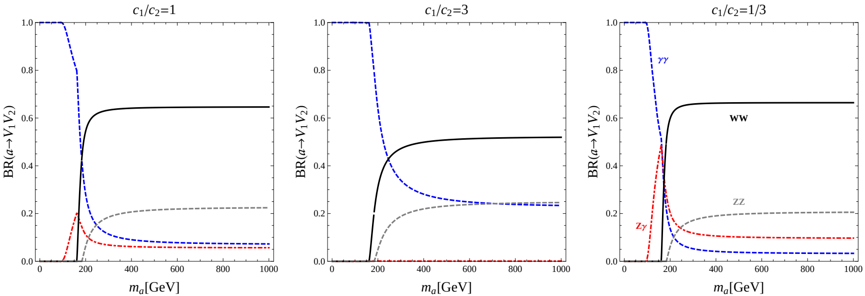
Conclusions

- We have studied a scenario that produces a new kind gamma-ray spectral feature. If observed unequivocal signal of dark matter.

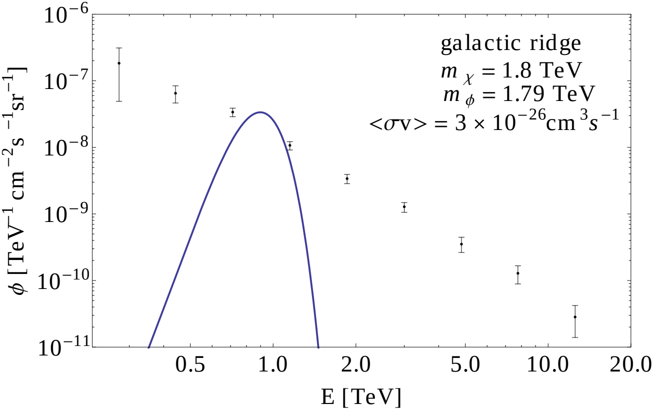
→ If not observed it constrains strongly such scenarios

- Gamma-ray boxes are an output of (simple) physical models for dark matter without circumventing difficulties such as fine tuning
- These can be probed with help of gamma-ray detectors as Fermi-LAT, H.E.S.S, CTA...

BR into vector bosons



H.E.S.S. data vs boxes



Constraints for different Δm