Dark matter constraints from box-shaped gamma-ray features

(arxiv:1205.0007)

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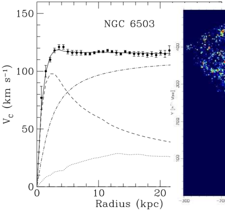
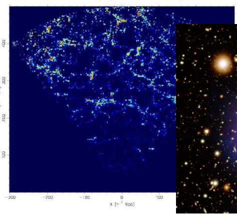
Outline

Evidences

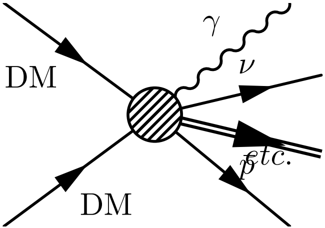
- There is an overwhelmingly ammount of evidences for the existance of Dark Matter (**DM**).

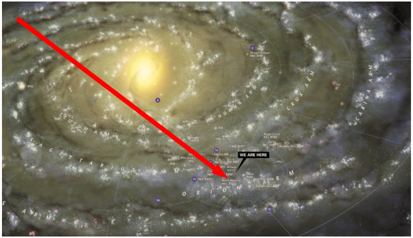





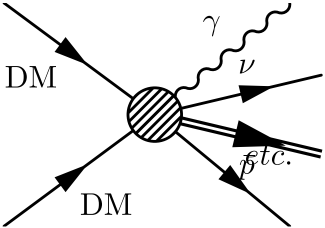

- The job we have now is to find out what its (mysterious) nature is.

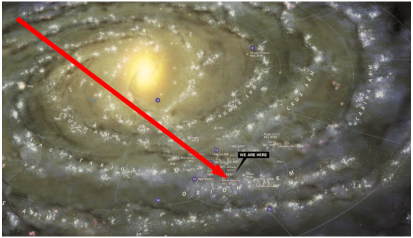
Indirect Detection





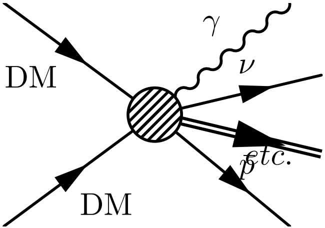
Indirect Detection

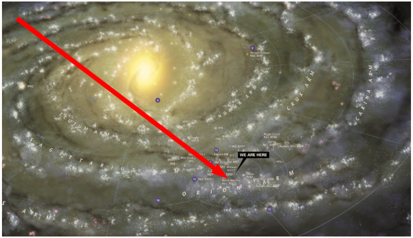




- Compute the expected flux of SM particles on earth
  - Antiprotons, Antideuterons...
  - Neutrinos
  - Gamma-rays

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

Indirect Detection

Identify Dark Matter through indirect observations:

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- Spectral features are a very clean way to spot Dark Matter
  → smoking-guns

Indirect Detection

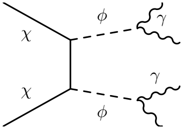
Identify Dark Matter through indirect observations:

- Spectral features are a very clean way to spot Dark Matter $\rightarrow$ smoking-guns
- Gamma-ray features:
  - Gamma-ray lines
  - Internal bremsstrahlung
  - Gamma-ray “boxes” (this talk)

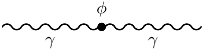
Box-shaped spectrum

- Consider a one-step cascade annihilation (or decay):

$$\chi\chi \rightarrow \phi\phi \Rightarrow \phi \rightarrow \gamma\gamma$$



$\rightarrow$



- Energy of the photons in the rest frame of ϕ: $E_\gamma^{\mathrm{RF}} = m_\phi/2$

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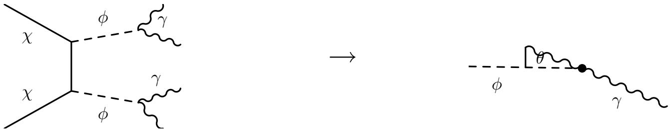

- Energy of the photons in the rest frame of ϕ: $E_\gamma^{\mathrm{RF}} = m_\phi/2$
- Momentum of the intermediate scalar $p_\phi = \sqrt{m_\chi^2 - m_\phi^2}$
- Energy of the photons in the lab frame

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

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

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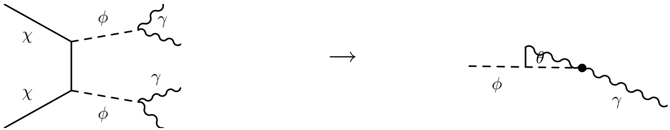
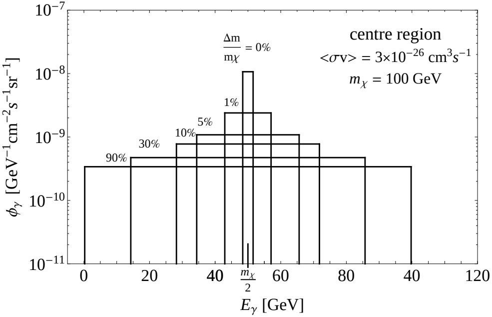
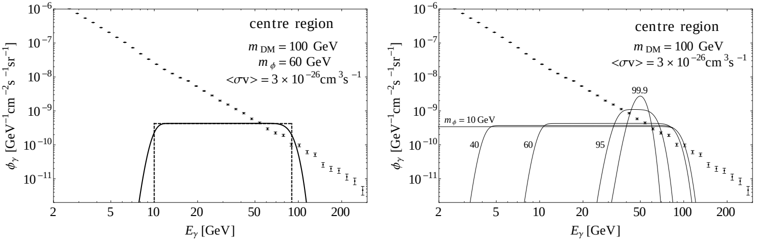




Observed flux

- Flux

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



- $\Delta m / m_\chi \to 0 \implies$ monochromatic line with 4γ
- $\Delta m / m_\chi \to 1 \implies$ dimmer but wider signal
- $E_C = m_\chi / 2$

Comparing models with experimental data

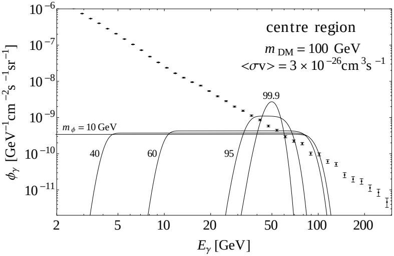
- The gamma-ray signal is characterized by the parameters

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

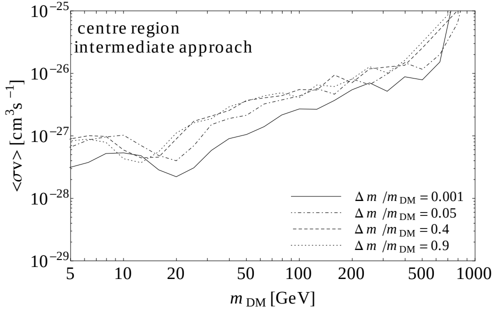
- We consider $BR(\phi \to \gamma\gamma) = 1$
- We derive limits at 95% C.L. from comparing $\phi_\gamma + \phi_{\gamma,b}$ to the Fermi-LAT data

Three approaches:

1. conservative $\to$ $\phi_{\gamma,\,b} = 0$
2. intermediate $\to$ $\phi_{\gamma,\,b} \propto E^{-\nu}$
3. aggressive $\to$ $\phi_{\gamma,\,b} = data$

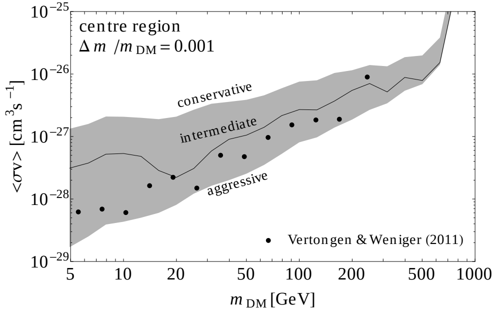


Constraints - annihilation



- The strongest constraints come from the degenerate case (gamma-line-like spectrum)
- Although LAT's highest energy bin is at 280 GeV, heavier DM particles are also strongly constrained
- Saturation from $\Delta m/m_\chi \gtrsim 0.05$

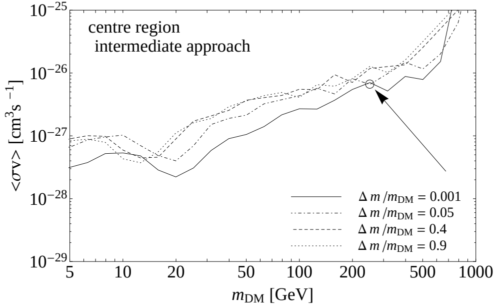
All three approaches



- Band encompasses almost two orders of magnitude at low masses and less than one at high masses
- Compare with constraints from gamma-ray lines:

$$\Delta m/m_\chi \to 0, \quad m_\chi \to m_\chi/2 \quad \& \quad 2\gamma \to 4\gamma$$

Accomodating the 130 GeV line



- Annihilating DM with $m_\chi \sim 260\,\mathrm{GeV}$ and Δm small enough reproduces the excess
- The cross-section for the process depends on $\mathrm{BR}(\phi \to \gamma\gamma)$ (For $\mathrm{BR} = 1 \to \langle \sigma v \rangle = 2.54 \times 10^{-27}\,\mathrm{cm}^3\mathrm{s}^{-1}$)
- Although this was not our aim, the 130 GeV excess can be elegantly explained with boxes

Concrete model

What do we need?

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- A stable DM particle χ

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Concrete model

What do we need?

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

Concrete model

H.M.Lee,M.Park,W.I.Park 1205.1675

Inspired in the Peccei-Quinn mechanism expand the G_{SM} with a $\mathrm{U(1)_{PQ}}$ global symmetry

- Introduce a fermion χ and a complex scalar field S both with a $\mathrm{U(1)_{PQ}}$ charge. The SM transforms trivialy under this group.

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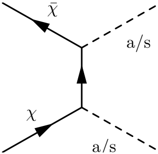
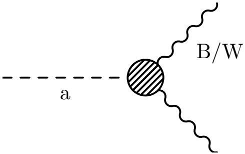
$$-\mathcal{L} \supset 2\lambda_{\mathrm{HS}}|S|^2|H|^2 - \lambda_\chi \left(S\bar{\chi}P_L\chi + S^*\bar{\chi}P_R\chi\right) - \sum_i \frac{c_i\alpha_i}{8\pi v_s} a F^a_{\mu\nu}\tilde{F}^{a\mu\nu}$$

- VEV of $\langle S\rangle = \frac{v_s}{\sqrt{2}} \rightarrow$ spontaneous breaking of $\mathrm{U(1)_{PQ}}$
- $S = v_s + s + ia$
- $m_s > m_\chi > m_a$





Conclusions

- We have studied a scenario that produces a gamma-ray spectral feature. If observed inequivocal signal of DM (perhaps already observed?). It circumvents some difficulties for $\langle \sigma v \rangle$ thanks to the tuning with BR.
- Scenarios with an annihilation cross-section equal to the thermal one can be probed using gamma-ray observations (providing the BR is sizeable).
- This scenario can be realized in concrete (simple) particle physics models.