γ-rays from Nearby Clusters: Constraints on Decaying Dark Matter for Selected Models

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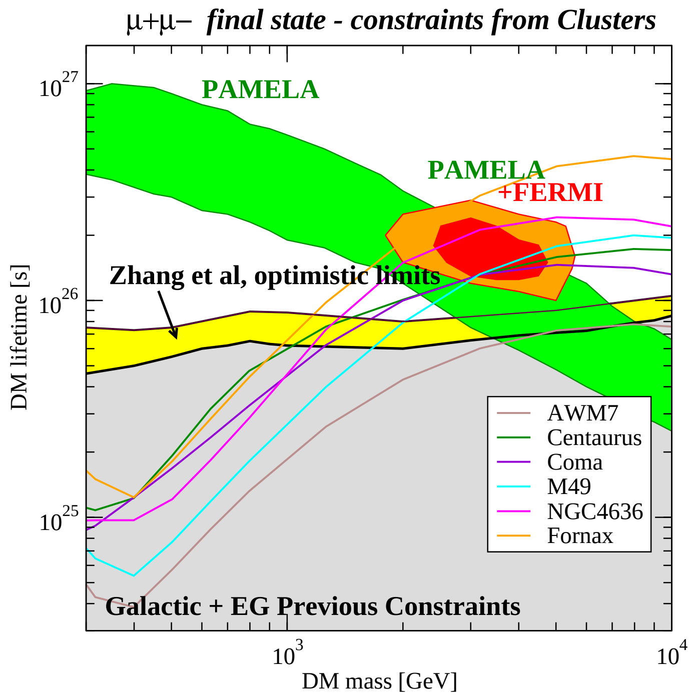
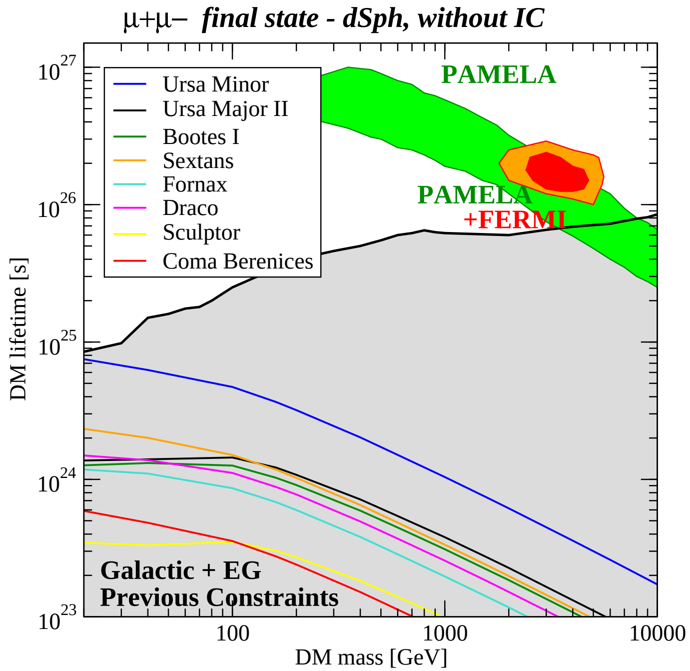
Outline

- Motivation and Background
- Astrophysics
- Decaying Dark Matter
- Phenomenologies
- Summary

Motivation





- **ArXiv:1009.5988v2 [astro-ph.HE]**
  - By Leanna Dugger, Tesla E. Jeltema, Stefano Profumo
- **Specific decay final states $\mu^+ + \mu^-$**
- **Constraints from nearby clusters and dwarf galaxies**

Previous works about clusters

Dark matter annihilation

- **JCAP 1005:025,2010**
  - By The Fermi-LAT Collaboration
- **Phys.Rev.D82:023506,2010**
  - By Qiang Yuan,Peng-Fei Yin,Xiao-Jun Bi,Xin-Min Zhang,Shou-Hua Zhu

Dark matter decay

- **ArXiv:1009.5988v2 [astro-ph.HE]**
  - By Leanna Dugger, Tesla E. Jeltema, Stefano Profumo

Clusters

NGC4636, M49, Fornax, Centaurus, AWM7 and Coma

- Highly dark matter dominated
- At high galactic latitude

Fermi-LAT observations of clusters

- ArXiv:1006.0748 [astro-ph.HE]
- From August 2008 to February 2010
- Within a 10° radius around the direction of each cluster
- In the range 0.2-100GeV
- Gamma-ray flux upper limits

Decaying Dark Matter-1

Possible interpretation for Pamela and Fermi-LAT excesses

- **Meta-stable**
  - Lifetime $\tau \sim 10^{27} s$
- **Mass** ~ 1 **TeV or even heavier**
  - For Fermi-LAT and H.E.S.S.
- **Quark-phobic final states**
  - 850 days observations (arXiv:1007.0821 [astro-ph.HE])
  - No anti-proton excess

Decaying Dark Matter-2

Possible meta-stable particle scenarios

- **Grand unification theory (GUT)**
  - Decays via GUT-suppressed dim-6 operators
- **Lightest superparticle**
  - Decays via R-parity violating operators
- **Non-perturbative**
  - Decays via instanton-induced operators
- **...**

We consider cluster photon upper flux limits here.

Cluster gamma-ray flux-1

- **Gamma-ray flux coming from a galaxy cluster**

$$\Phi(E_\gamma) = C \times J(\psi) \times W(E_\gamma)$$

- $J(\psi)$ **encodes the astrophysical information**

$$J(\psi) = \int_{\triangle\Omega} d\Omega \int_0^\infty dl(\psi)\rho_{DM}(l)$$

- **A** 10° **radius around the direction of each cluster**

$$J(\psi) \simeq \frac{1}{D^2}\int dV \rho_{DM}(l) = \frac{M_{200}}{D^2}$$

  - Independent of dark matter density profile
  - Independent of substructure uncertainty

Cluster gamma-ray flux-2

Final state radiations

- **Bremsstrahlung, π^0 decay and so on**

$$\Phi(E_\gamma) = \frac{M_{200}}{4\pi D^2} \sum_i \frac{\Gamma_i^{DM}}{M^{DM}} \frac{dN_i^{DM}}{dE_\gamma}$$

Inverse Compton scattering

- $e + \gamma \to e + \gamma$

$$\Phi(E_\gamma) = \frac{M_{200}}{4\pi D^2} \sum_i \frac{\Gamma_i^{DM}}{M^{DM}} \int_0^\infty d\epsilon f_{CMB}(\epsilon) \int dE_e \frac{d\sigma^{ICS}(E_e, \epsilon)}{dE_\gamma} \frac{dN_i^{DM}(E_e)}{dE_e}$$

SUSY SU(5) model-1

Minimal extension: SU(5) singlet S as dark matter candidate

- Z_2 symmetry: S is odd, others are even,
  to suppress dim-5 operators

Dim-6 operators

$$\frac{S^{+}S\overline{5}^{+}\overline{5}}{M_{GUT}^{2}}, \quad \frac{S^{+}STr(10^{+}10)}{M_{GUT}^{2}}$$

- Superfields: $S(y) = \tilde{s}(y) + \sqrt{2}\theta s(y) + \theta^2 F_s(y)$

$$\overline{5}^T = (d^c, d^c, d^c, e, -\nu)_L$$

$$10 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & u^c & -u^c & u & d \\ -u^c & 0 & u^c & u & d \\ u^c & -u^c & 0 & u & d \\ -u & -u & -u & 0 & e^c \\ -d & -d & -d & -e^c & 0 \end{pmatrix}_L$$

SUSY SU(5) model-2

To make S decay

- Assuming the scaler get a vev $\langle\tilde{s}\rangle$, Z_2 symmetry is spontaneously broken.

Operators in component fields

$$\sum_{\Phi}\frac{1}{M_{GUT}^2}\left(i<\widetilde{s}>\widetilde{s}^*(\partial_\mu\psi\sigma^\mu\bar{\psi})+i<\widetilde{s}>\widetilde{\psi}^*(\partial_\mu\psi\sigma^\mu\overline{s})+<\widetilde{s}>\widetilde{s}^*\widetilde{\psi}^*\Box\widetilde{\psi}\right)+h.c.+...$$

... denotes the terms which can be dropped

- Total divergence terms
- Operators from F terms
  - suppressed by the leptonic Yukawa coupling constant
  - leading to many body decays which are further suppressed by phase spaces

SUSY SU(5) model-3

Dark matter decays dominantly via $\widetilde{s}^{*}\widetilde{\psi}^{*}\Box\widetilde{\psi}$

- For $\widetilde{s}^{*}(\partial_{\mu}\psi\sigma^{\mu}\bar{\psi})$, $\Gamma \propto m_{\psi}^{2}$
  - dominant decay channel is $\widetilde{s} \to t\bar{t}$
  - suppressed by m_{t}^{2}/m_{s}^{2}
- For $\widetilde{\psi}^{*}(\partial_{\mu}\psi\sigma^{\mu}\bar{s})$, $\Gamma \propto m_{\psi}^{2}$
  - dominant decay channel is $s \to \tau\widetilde{\tau}$
  - suppressed by m_{τ}^{2}/m_{s}^{2}

$\widetilde{s}$ decays dominantly into a slepton pair if

- the squark masses are heavier than the DM mass $m_{\widetilde{s}}$
- the slepton masses to be around several hundred GeV

SUSY SU(5) model-4

The operator can be rewritten as

$$\sum_{\tilde{l}} \frac{-1}{M_{GUT}^2} < \tilde{s} > \tilde{s}^* (\widetilde{l_L}^* \Box \widetilde{l_L} + \widetilde{l_R} \Box \widetilde{l_R}^*), \quad (\tilde{l} = \tilde{e},\ \tilde{\mu},\ \tilde{\tau})$$

with the decay width

$$\Gamma_{\tilde{l}} = \frac{\sqrt{M_s^2 - 4M_{\tilde{l}}^2} < \tilde{s} >^2 M_{\tilde{l}}^4}{16\pi M_s^2 M_{GUT}^4}$$

- $\tau_{\tilde{s}} \sim 10^{26}$s, with $m_s \sim < \tilde{s} > \sim$ TeV and $M_{\tilde{l}} \sim$ several hundred GeV

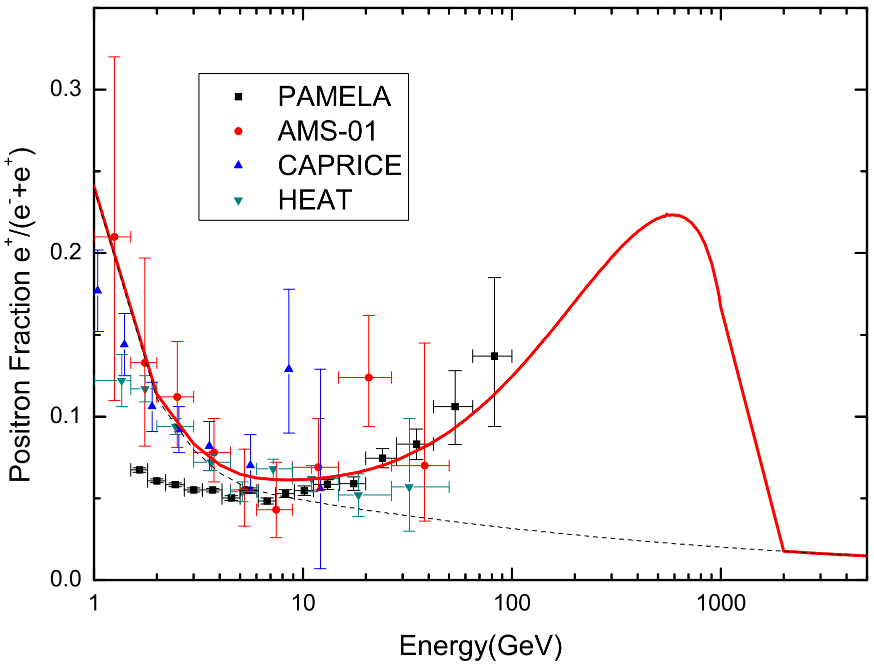
With R-parity conservation, $e^{\pm}$ and γ can be produced from $\tilde{s} \to \tilde{l}^+ \tilde{l}^-$(using PYTHIA)

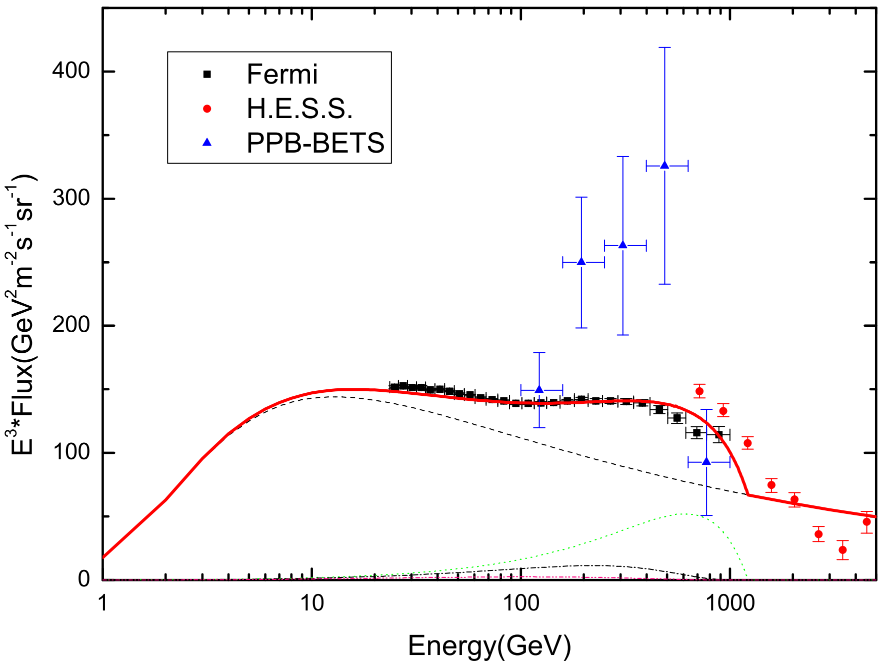
- selectron chain: $\tilde{s} \to \tilde{e} \to e$
- smuon chain: $\tilde{s} \to \tilde{\mu} \to \mu \to e$
- stau chain: $\tilde{s} \to \tilde{\tau} \to \tau \to e$

Fit the PAMELA and Fermi-LAT excesses

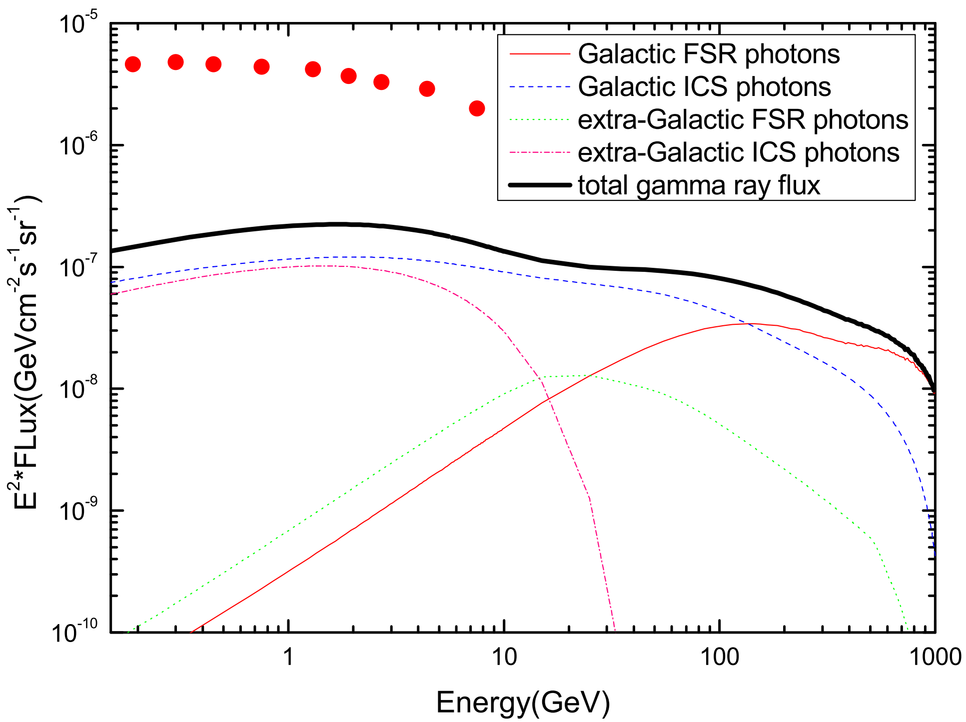
Parameter set

$M^{DM} = 6.5$ TeV, $M_{GUT} = 10^{16}$ GeV, $< \tilde{s} >= 20$ TeV,
$M_{\tilde{e}} = 380$ GeV, $M_{\tilde{\mu}} = 370$ GeV, $M_{\tilde{\tau}} = 330$ GeV, $M_{LSP} = 300$ GeV



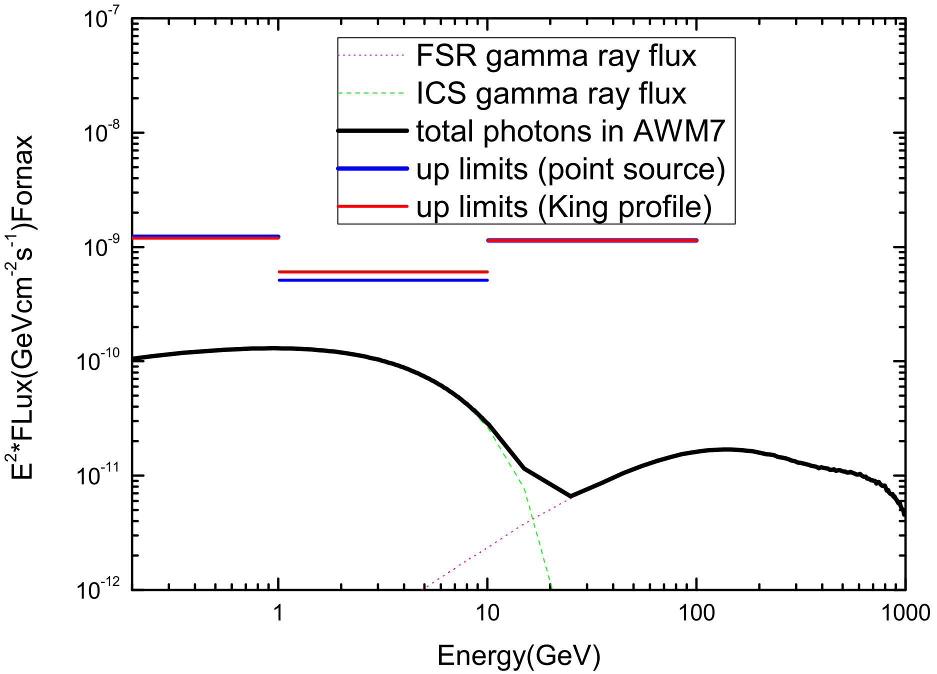


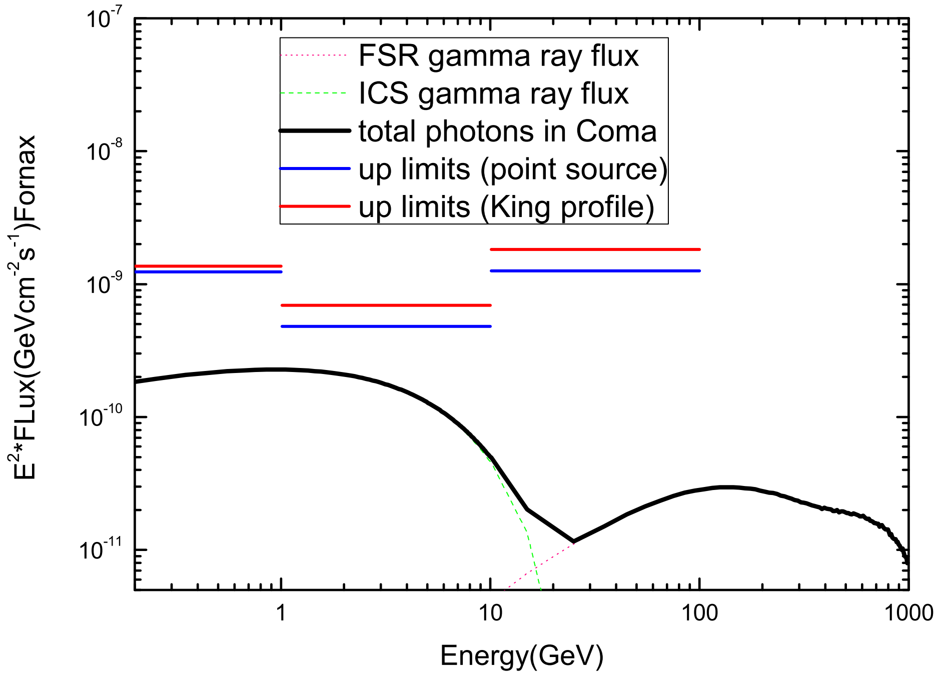
γ-flux in the region $0^\circ \leq l \leq 360^\circ, 10^\circ \leq |b| \leq 20^\circ$



- **Dark matter signals: almost 2-order below the observation**
- **Phys.Lett.B688:216-223,2010.**

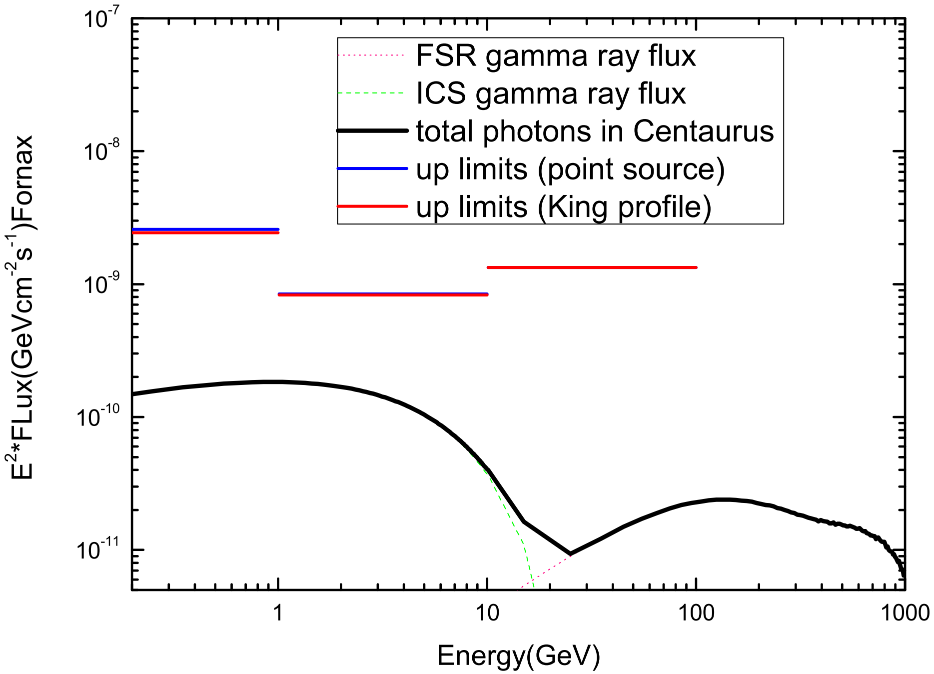
γ-flux from AWM7 and Coma

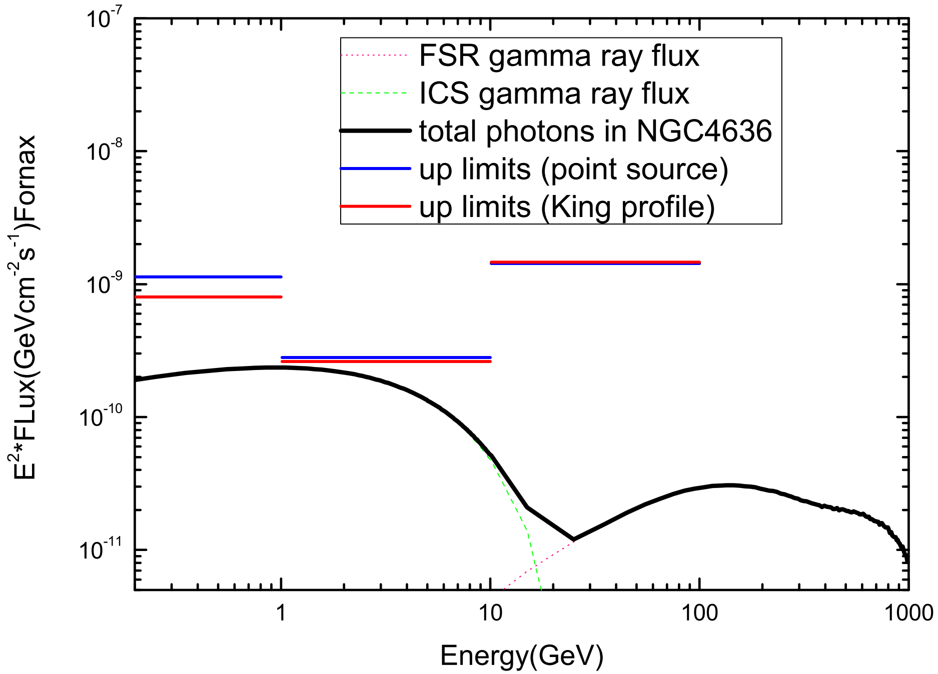




- **Consistent with the Fermi-LAT data**

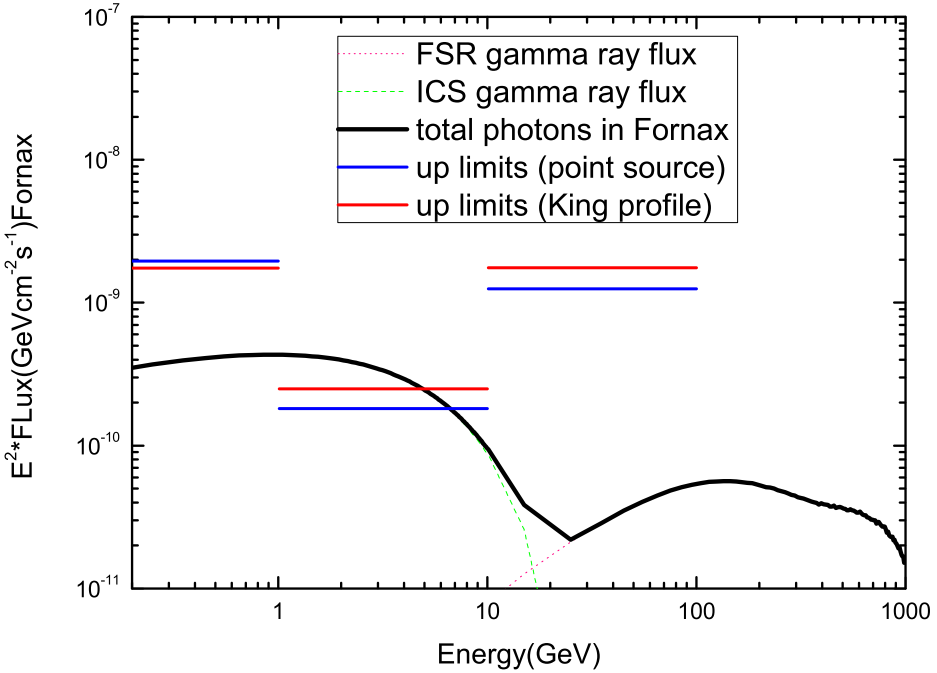
γ-flux from Centaurus and NGC4636

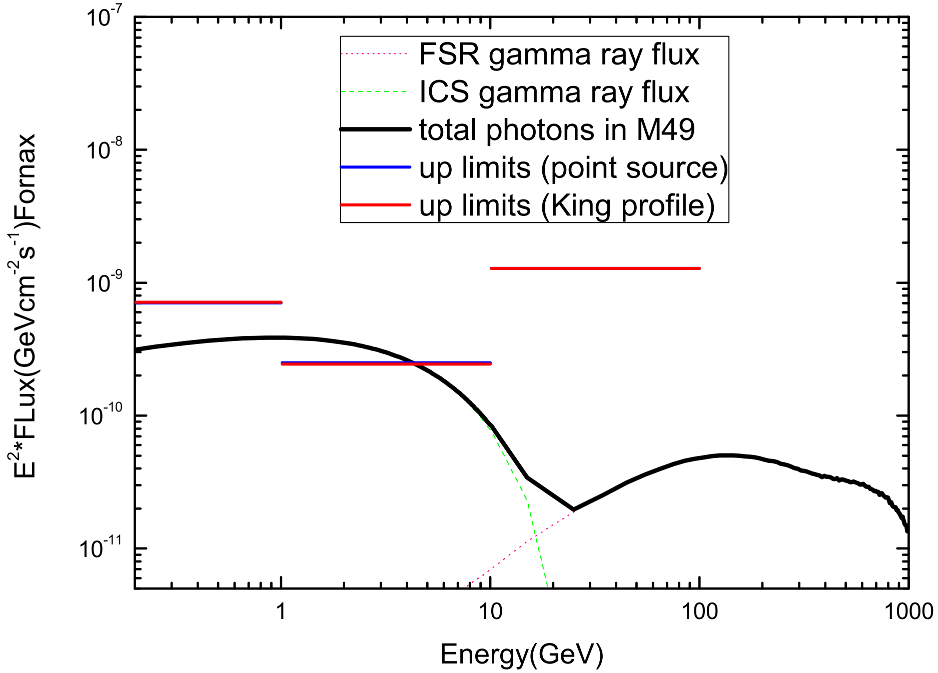




- Consistent with the Fermi-LAT data

γ-flux from Fornax and M49





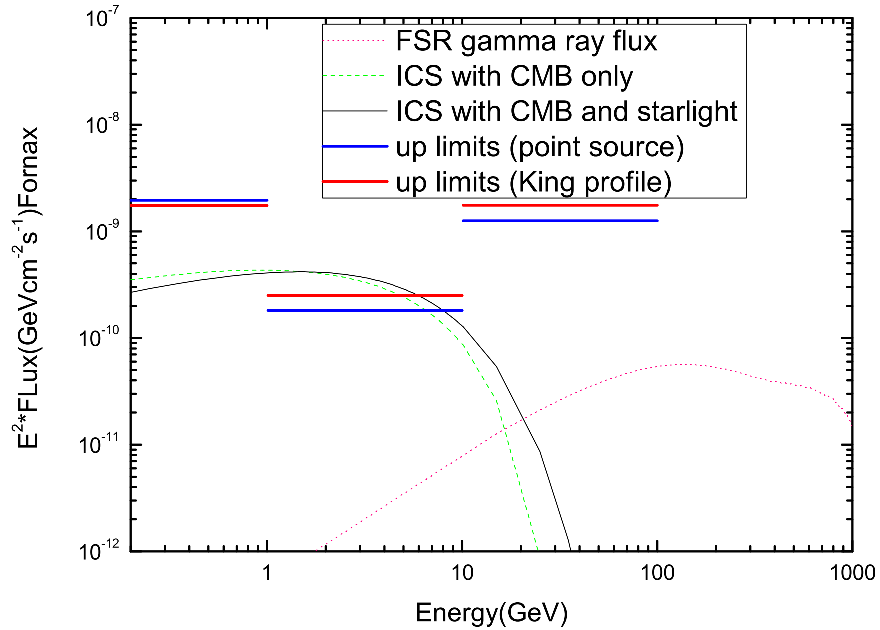
- **Rule out**
- **Fornax: the strongest constraint**

Cluster uncertainties-1

Gamma-ray background

- **A toy model about Fornax starlight**

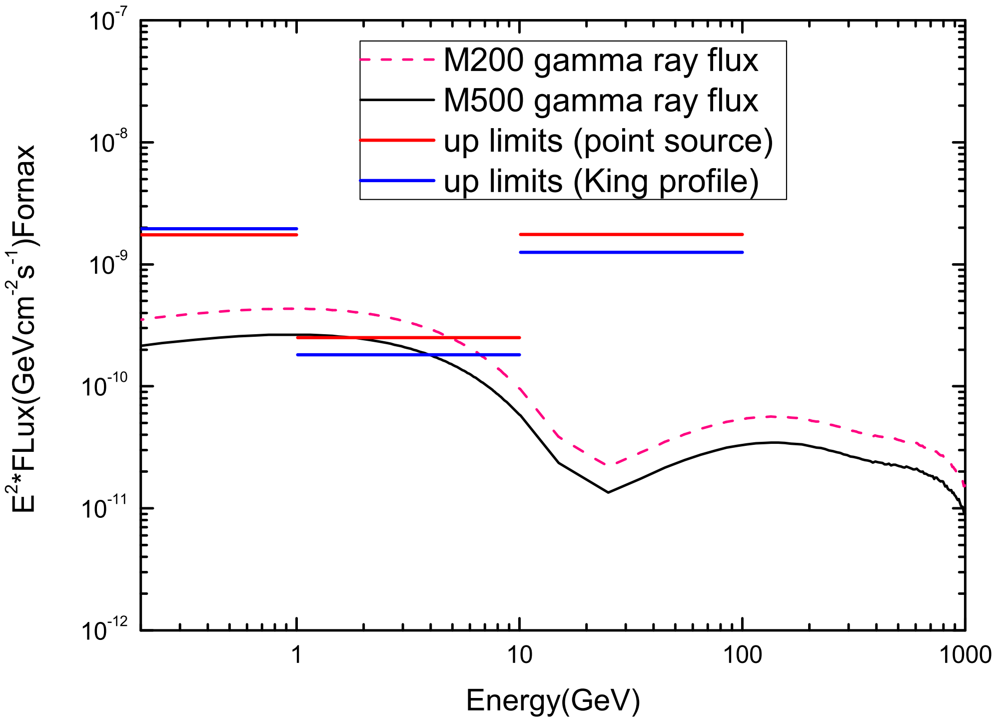
$$\frac{n_{Fornax}}{n_{Milky}} = \frac{L_{Fornax}/R^3_{Fornax}}{L_{Milky}/R^3_{Milky}}$$



Cluster uncertainties-2

Cluster Mass

- **Fornax Mass** M_{500}

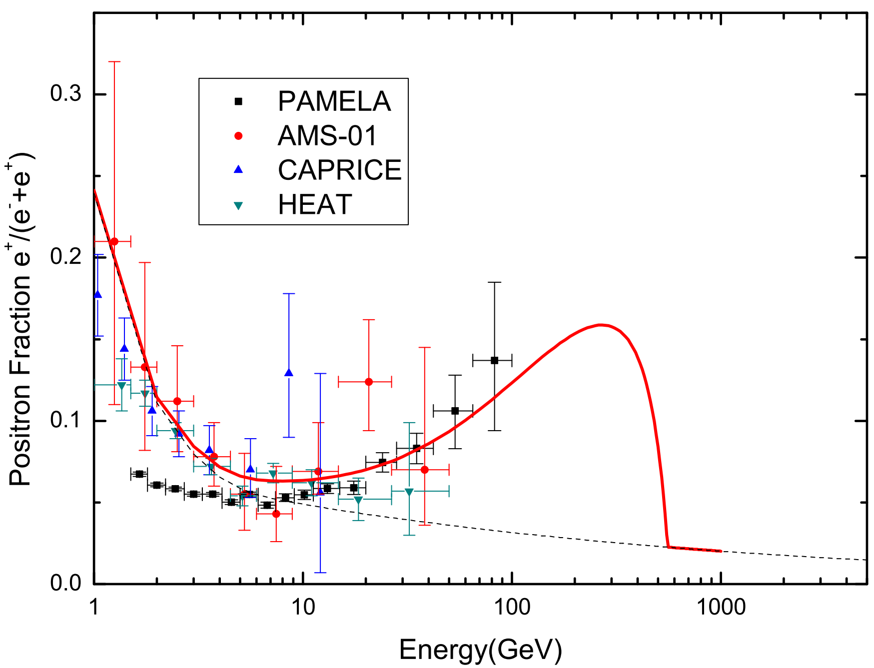


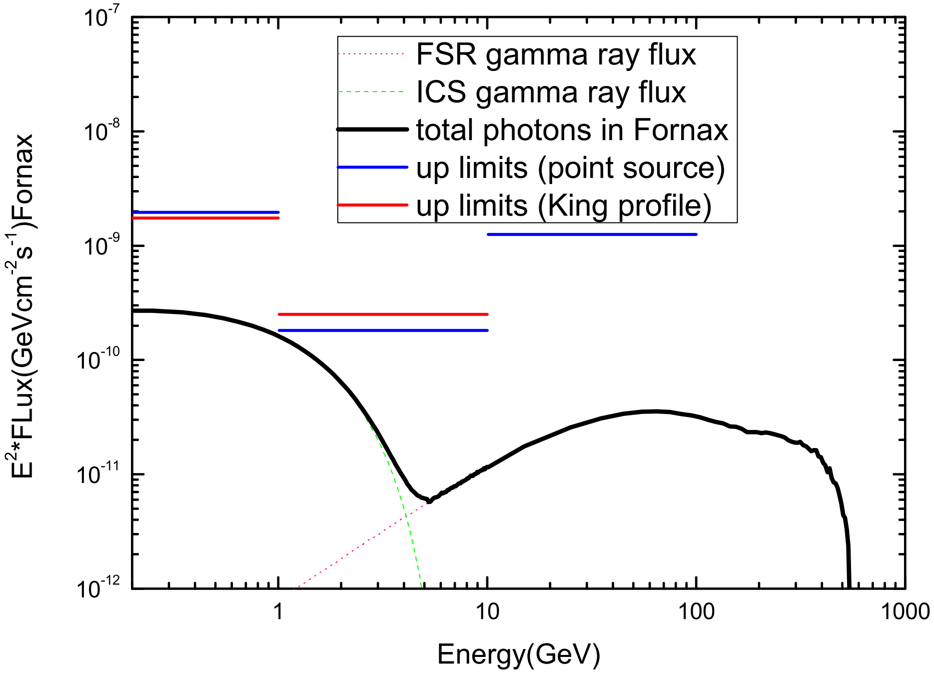
only fit the PAMELA anomaly

A new parameter set

$M^{DM} = 3$ TeV, $M_{GUT} = 10^{16}$ GeV, $<\tilde{s}>= 11$ TeV,

$M_{\tilde{e}} = 380$ GeV, $M_{\tilde{\mu}} = 370$ GeV, $M_{\tilde{\tau}} = 330$ GeV, $M_{LSP} = 300$ GeV





Summary

- A SU(5) singlet S as dominant DM candidate
- S decays with lifetime around 10^{26}s
  - via GUT suppressed dim-6 effective operators
  - Spontaneously broken Z_2 symmetry by a TeV scale vev $\langle \tilde{s} \rangle$
- Fit Pamela and Fermi-LAT excesses
  - Fail to escape from cluster γ-ray flux upper limits
  - Fornax cluster gives the strongest constraint
  - Cluster constraints improve on previous γ-ray constraints
- Fit Pamela anomaly only
  - Consistent with the observation
- Other models need to be checked(in progress)

Thank you!