130GeV gamma-ray line and dark matter

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CTA研究会＠東京大学宇宙線研究所(2012/9/26)

Contents

- Evidence for 130GeV gamma-ray line
- Models to explain 130GeV gamma
- Future prospects

130GeV line ?

- C.Weniger, 1204.2797
  - Analyzed 43months Fermi data 20-300GeV.
  - Chose sky regions that optimize DM signal for several DM halo profiles.

    (Background count from 1-20GeV data)
  - Performed spectral analysis for chosen sky region

$$\frac{dF}{dE} = S\delta(E - E_\gamma) + \beta \left(\frac{E}{E_\gamma} \right)^{-\gamma}$$

  - Claimed 4.6σ evidence for 130GeV line (3.2σ after look-elsewhere effect)

$$m_\chi \simeq 129.8\mathrm{GeV} \qquad \langle \sigma v \rangle_{\gamma\gamma} \simeq 1.27 \times 10^{-27} \mathrm{cm}^3/\mathrm{s}$$

1: Cored isothermal

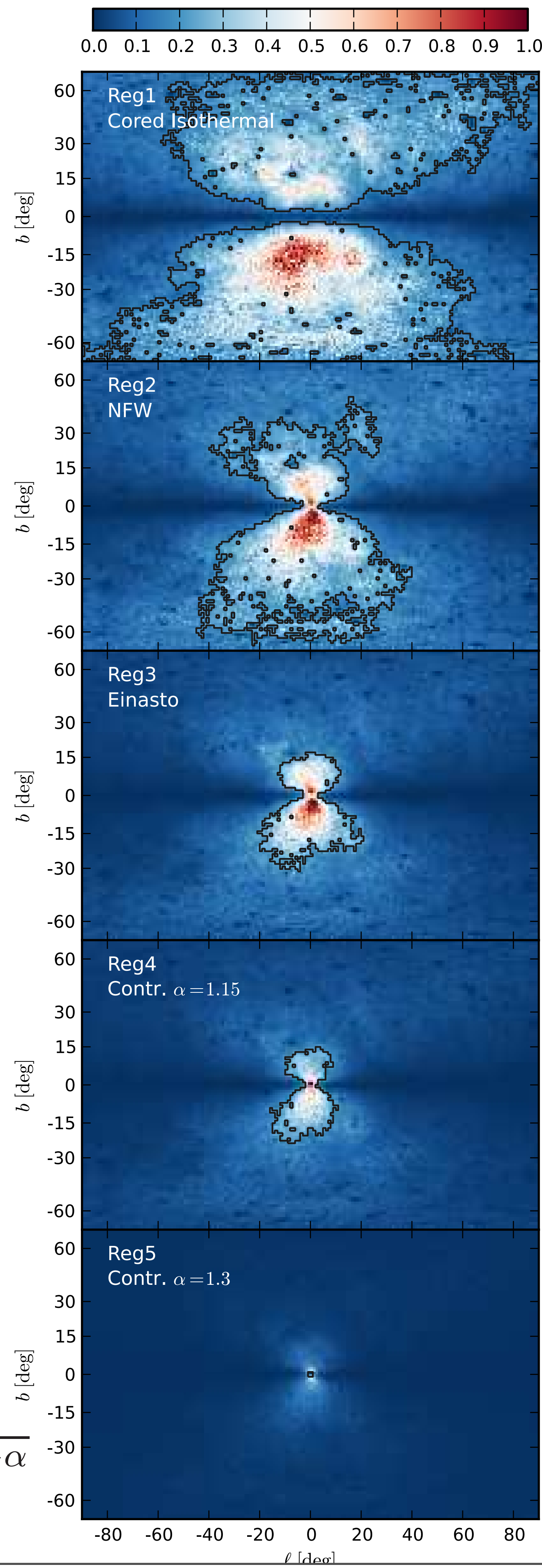
2: NFW

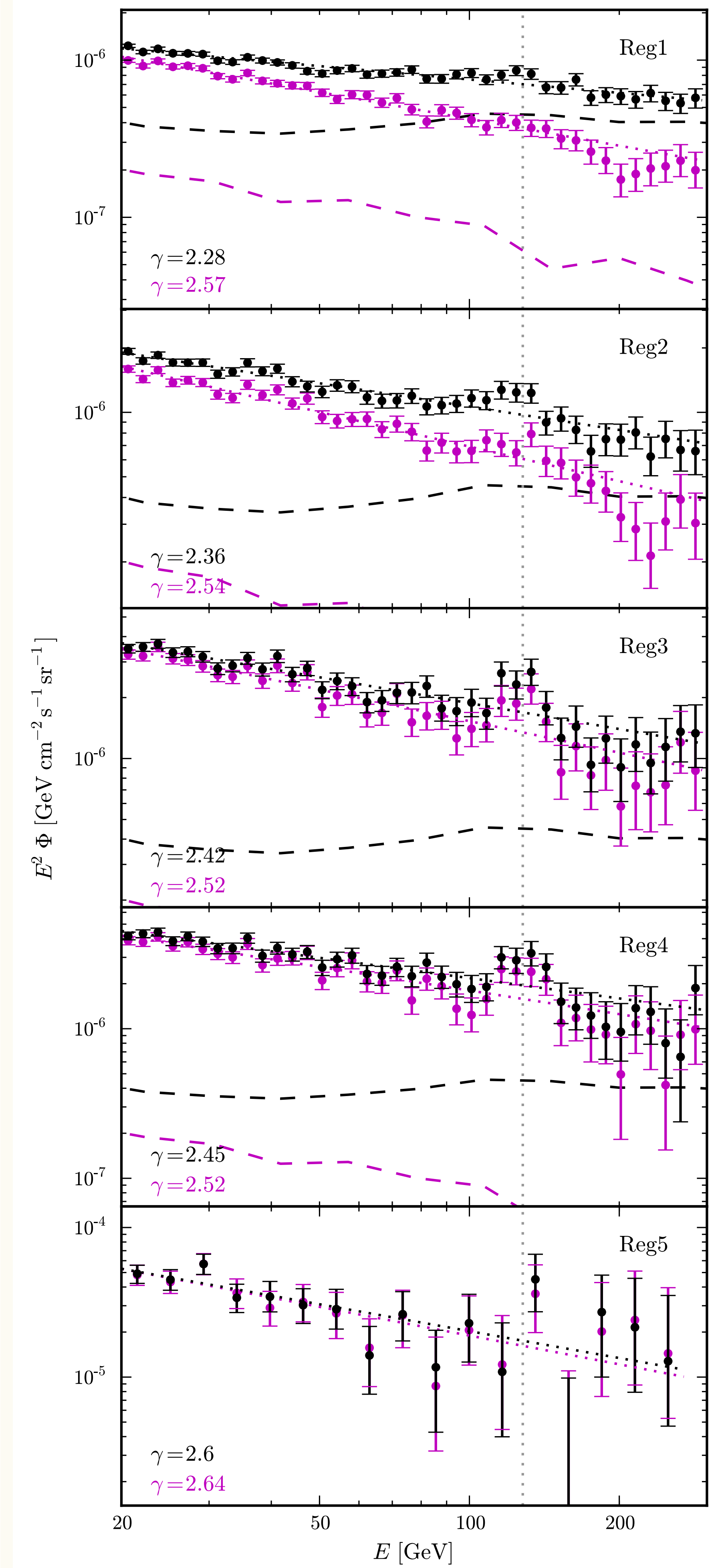
3: Einasto

4: Contr, α=1.15

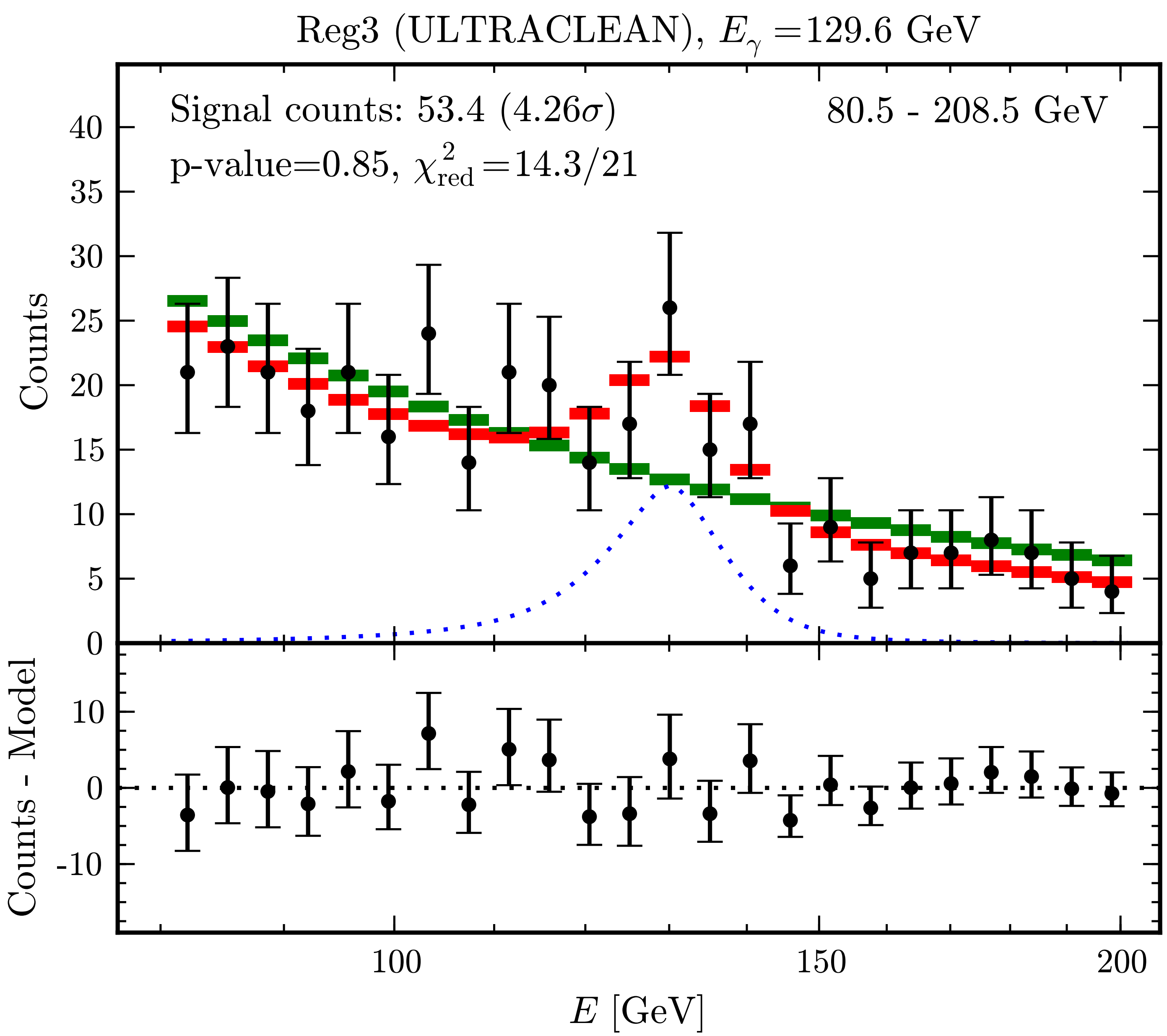
5: Contr, α=1.3

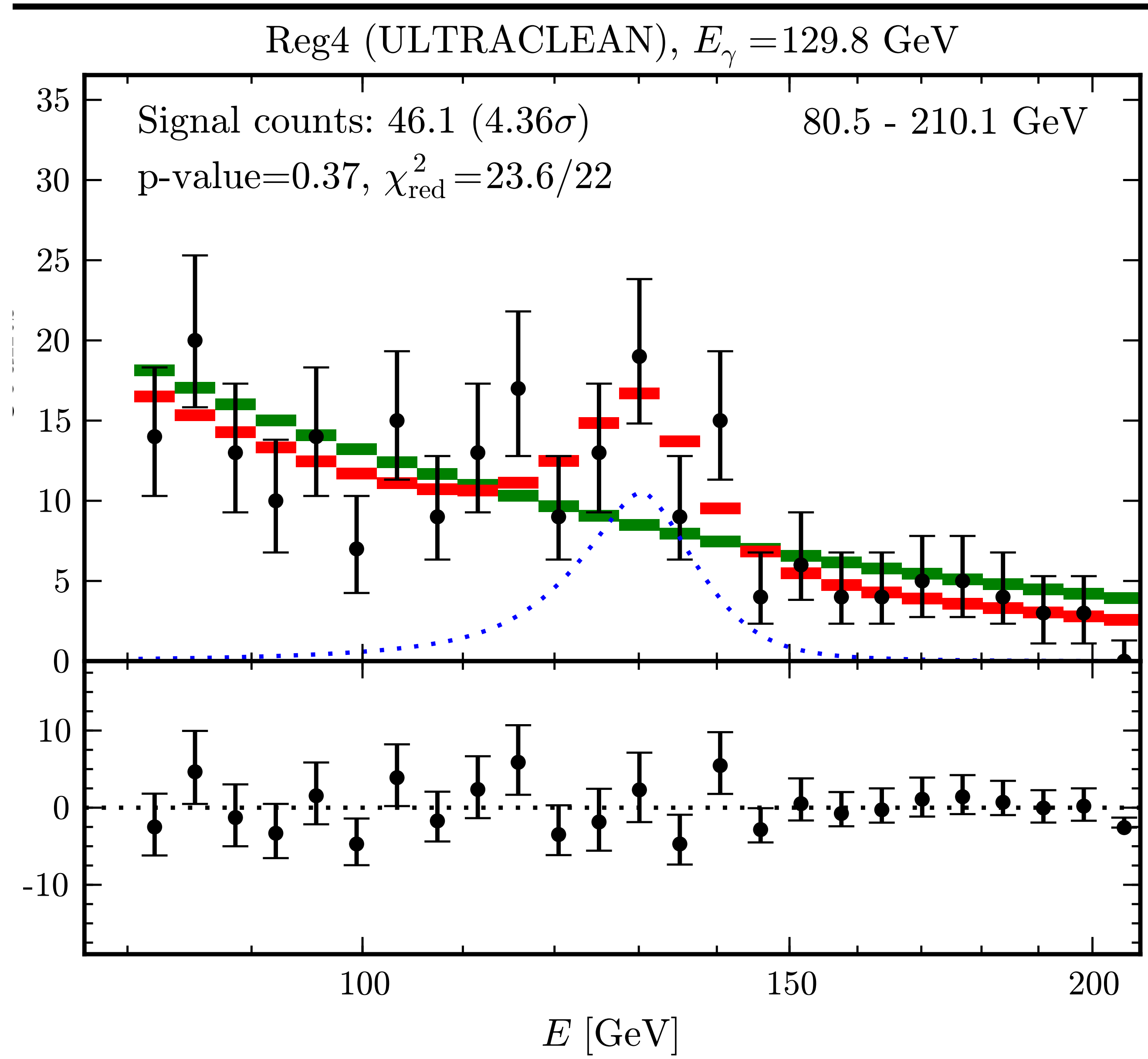
$$\rho_{\rm dm}(r) \propto \frac{1}{(r/r_s)^{\alpha}\,(1+r/r_s)^{3-\alpha}}$$





Region3 Region4

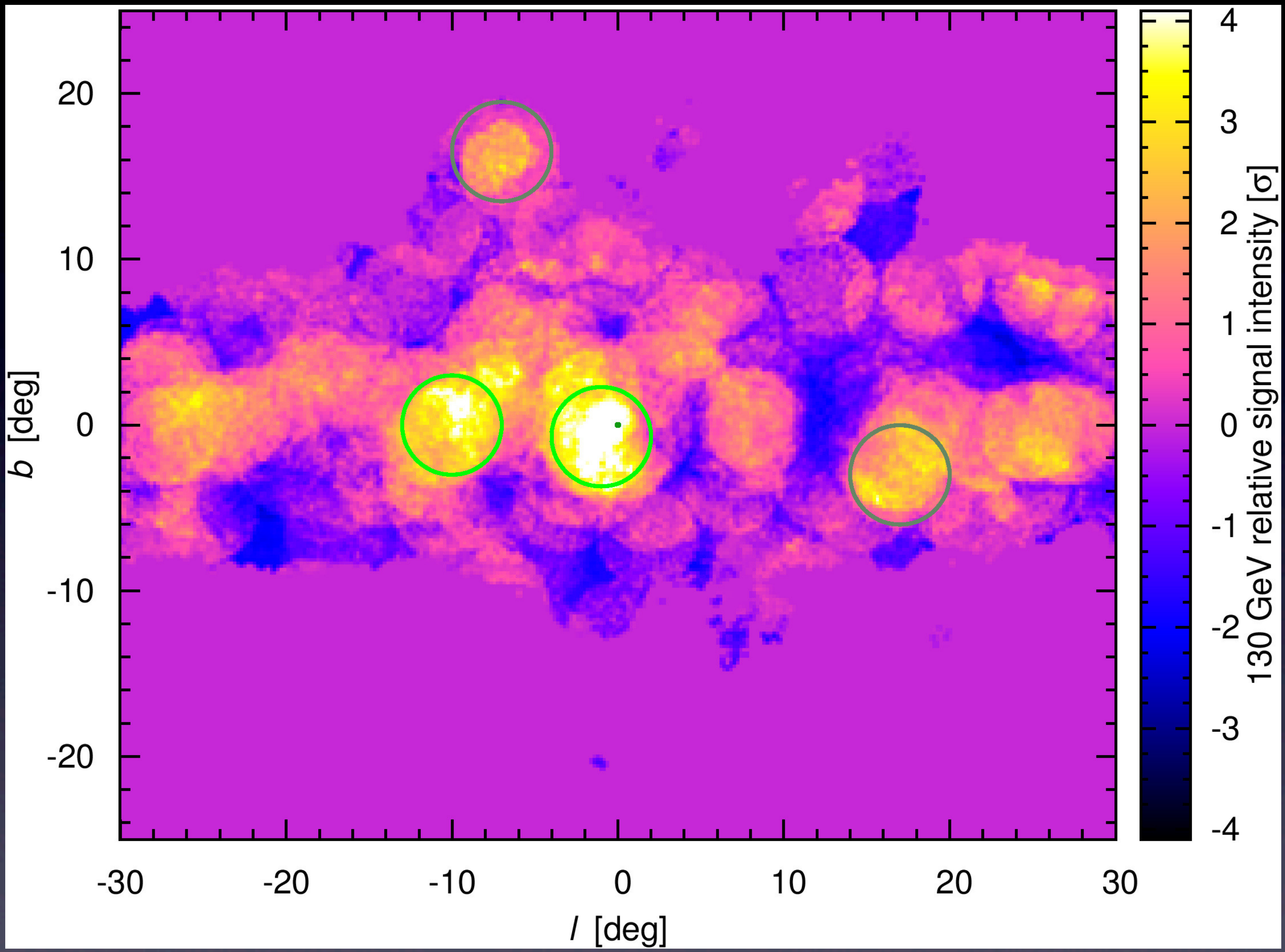




red : best fit with DM
green : best fit without DM

- Profumo, Linden, 1204.6047
  - The excess region overlaps with Fermi bubble
  - Broken power law component from Fermi bubble can mimic the 130GeV gamma line
- Tempel, Hektor, Raidal, 1205.1045
  - 195week Fermi data : 130GeV excess with 4.5σ
  - No artificial choice of the signal region
  - The excess is not correlated with Fermi bubble
- Fermi-LAT collaboration, 1205.2739
  - 2 years data with $|b| > 10^\circ$ + $20^\circ \times 20^\circ$ around GC
  - No excess in 4.8GeV - 264GeV

Distribution of relative signal intensity of 130GeV photons



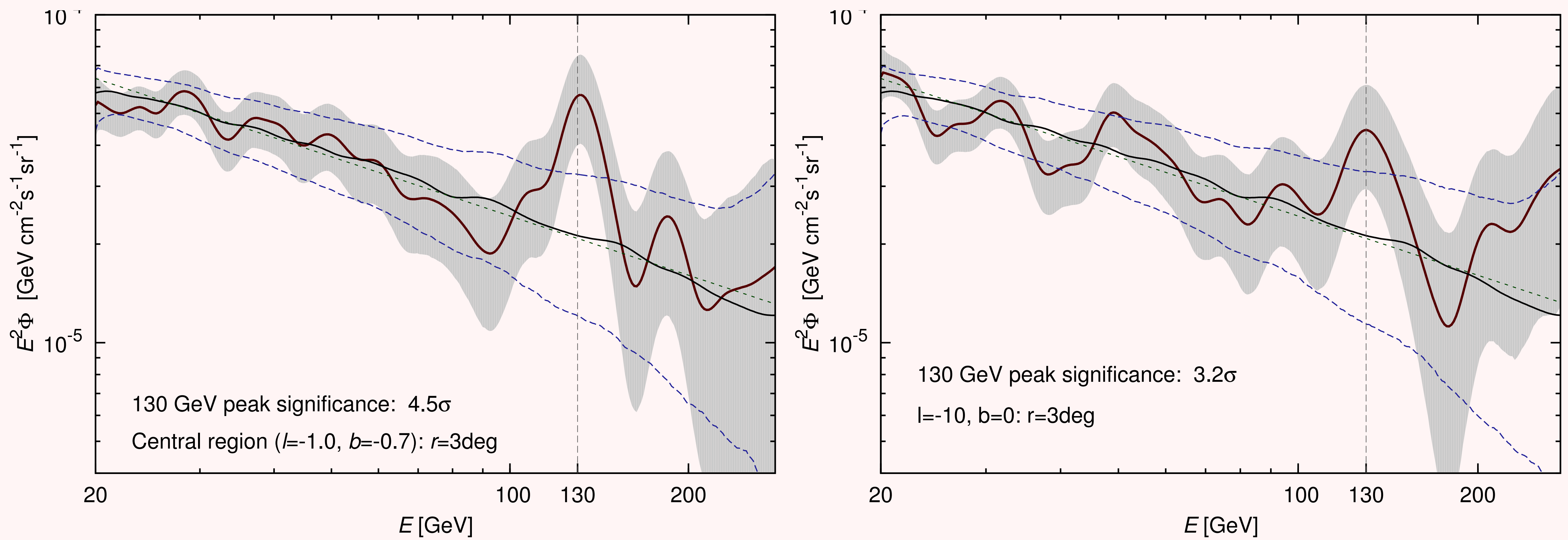
Excess : ~4σ ⟶ True excess?

Deficit : ~2σ ⟶ Statistical fluctuation?

Tempel, Hektor, Raidal, 1205.1045

Tempel, Hektor, Raidal, 1205.1045

Region	l (deg)	b (deg)	N_γ (20–300) GeV	N_γ (120–140 GeV)	significance
Weniger Reg3	–	–	3298	65	3.6σ
Central	-1	-0.7	818	27	4.5σ
West	-10	0	726	21	3.2σ
East	17	-3	481	14	2.7σ
North	-7	16.5	109	4	1.6σ



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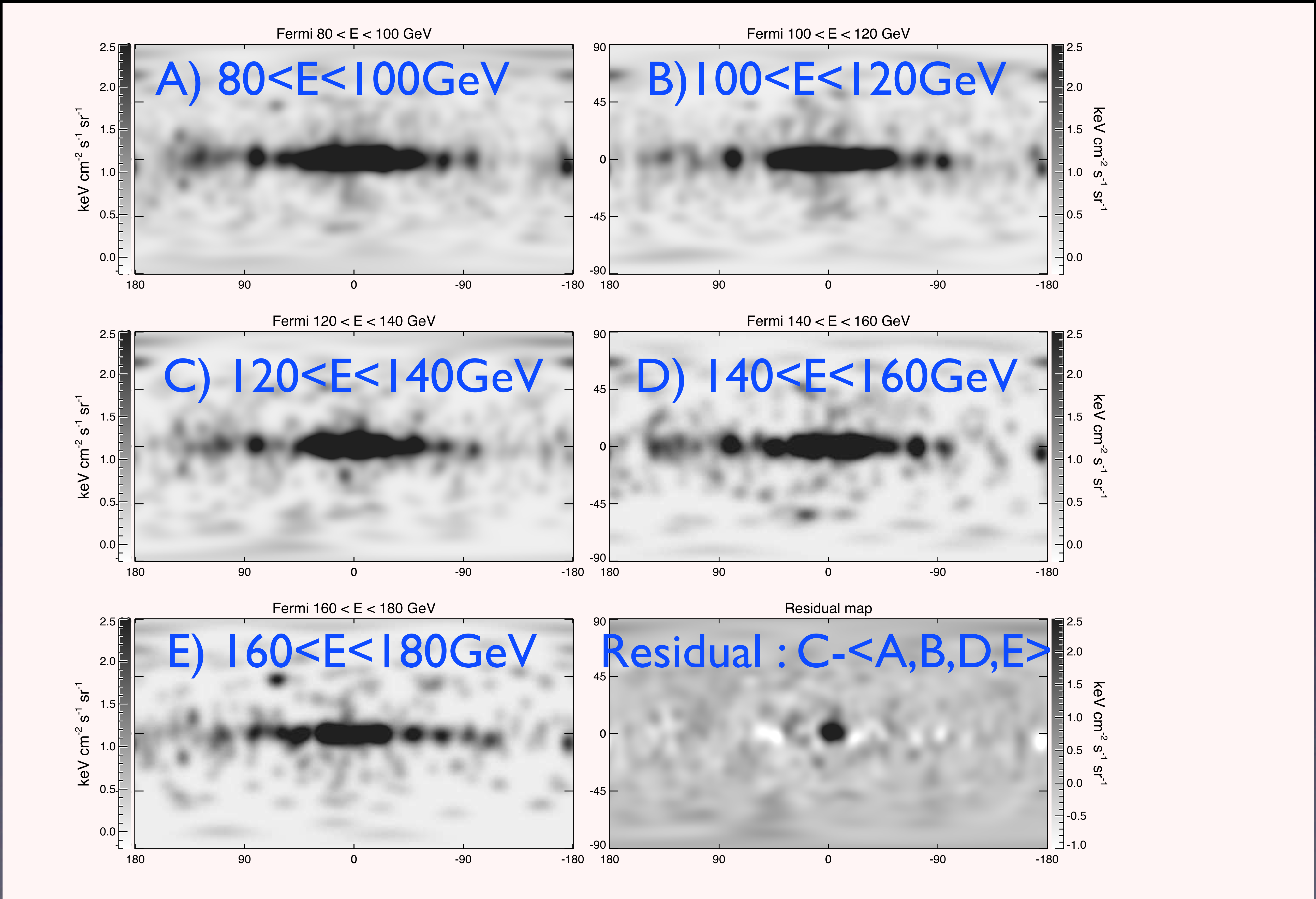
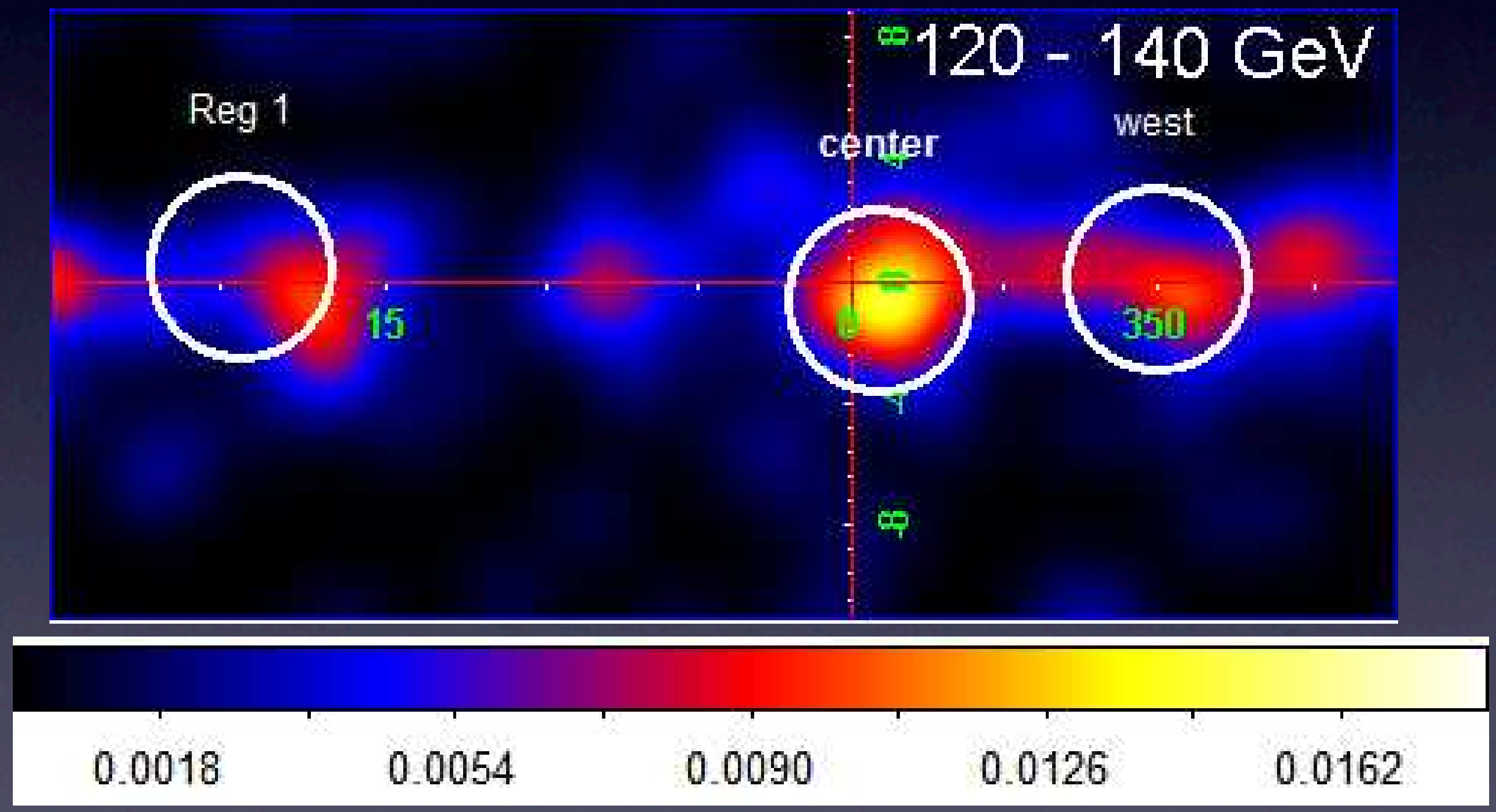
- Boyarsky, Malyshev, Ruchayskiy, 1205.4700
  - 3.7years Fermi data
  - Significant spatial variations in excess and dip
  - Dark matter interpretation is "dubious"
- Su, Finkbeiner, 1206.1616
  - 3.7years Fermi data
  - 6.5σ evidence for existence of line excess
- Hektor, Raidal, Tempel, 1207.4466
  - 130GeV gamma from 6 clusters (3.2σ)
- Hektor, Raidal, Tempel, 1209.4548
  Finkbeiner, Su, Weniger, 1209.4562
  - Effects of Earth limb photon is insignificant

- Su, Finkbeiner, 1206.1616



Models to explain 130GeV line

- Aharonian, Khangulyan, Malyshev, 1207.0458
  - They analyzed 52month Fermi data in regions claimed by Tempel et al., Boyarsky et al., Su et al. and confirmed excess of ~130GeV gamma.



  - Inverse-Compton by electrons from cold pulsar wind can produce gamma “line” at ~130GeV.

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The idea

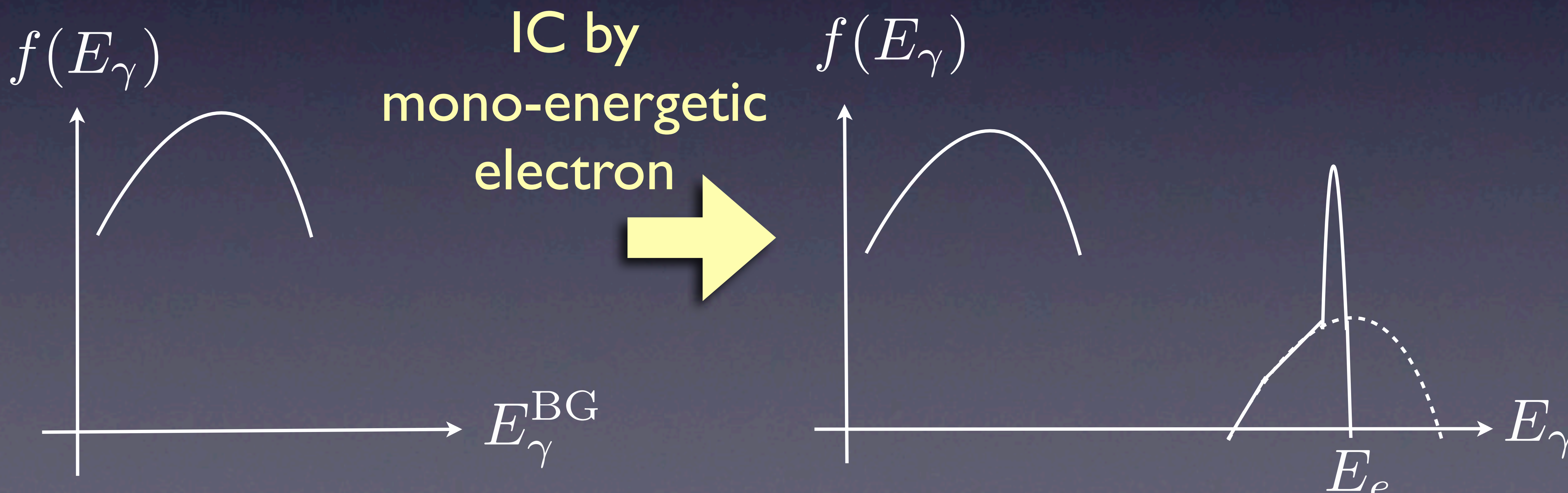
Inverse-Compton process $e + \gamma^{\rm BG} \to e + \gamma$

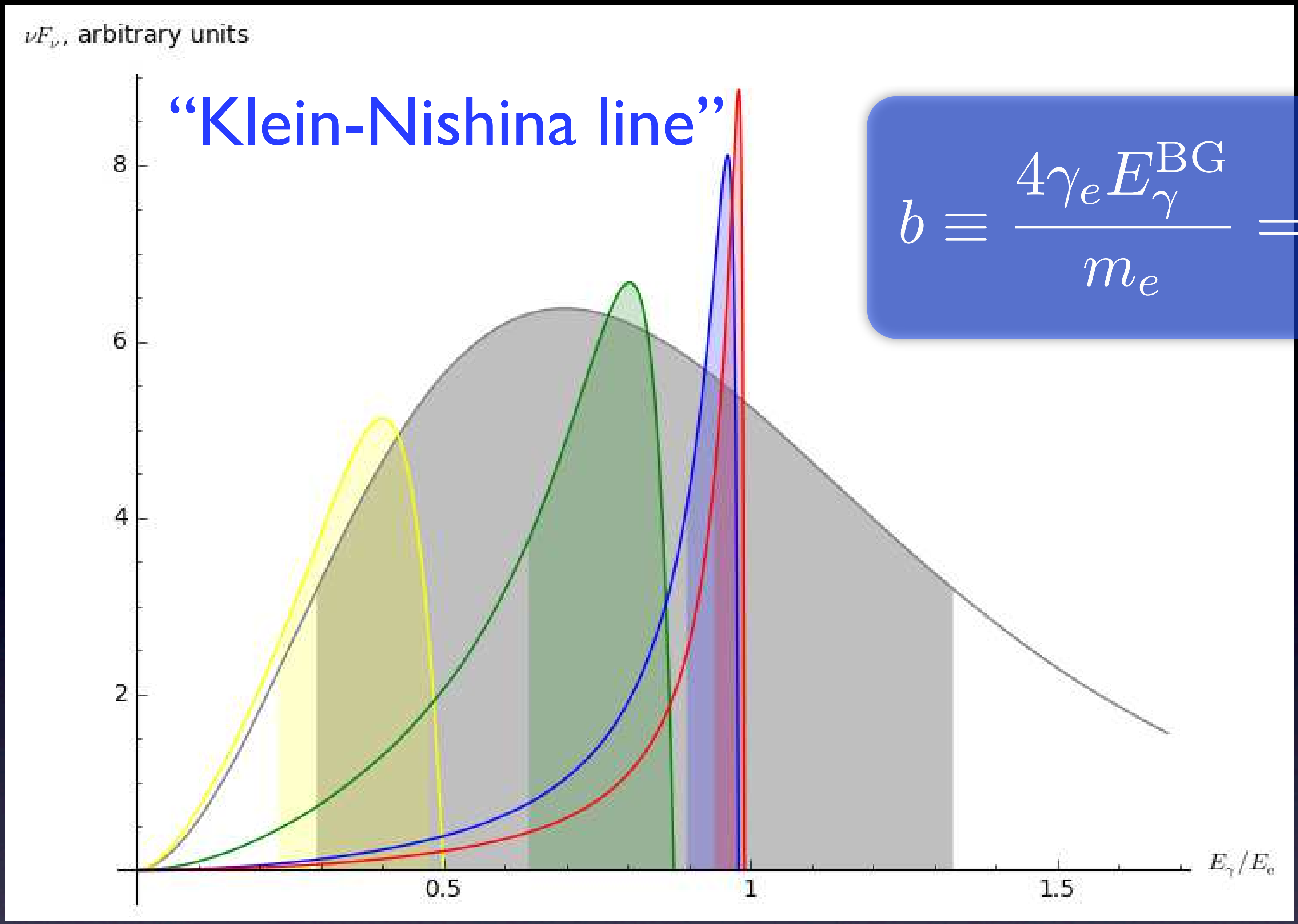
Energy of upscattered photon :

$$E_\gamma \sim \gamma_e^2 E_\gamma^{\rm BG} \quad \text{for } \gamma_e E_\gamma^{\rm BG} \ll m_e \qquad \text{(Thomson regime)}$$

$$E_\gamma \sim E_e = \gamma_e m_e \quad \text{for } \gamma_e E_\gamma^{\rm BG} \gg m_e \qquad \text{(Klein-Nishina)}$$

$(\gamma_e \ : \ \text{Lorentz factor of incident electron})$





$$b \equiv \frac{4\gamma_e E_\gamma^{\rm BG}}{m_e} = 1, 7, 50, 100$$

$$b > 30 \leftrightarrow \Delta E_\gamma / E_\gamma < 15\%$$

$$E_\gamma^{\rm BG} > 15\,{\rm eV} \left(\frac{130{\rm GeV}}{E_\gamma}\right)$$

- Thermal emission from neutron star (single pulsar) ?
- or from companion star (binary systems) ?

Dark matter

- Many models after Weniger(2012) (~40 paper)
- Required cross section $\langle \sigma v \rangle_{\gamma\gamma} \simeq 1.27 \times 10^{-27} \mathrm{cm}^3/\mathrm{s}$ is smaller than the value for correct relic abundance.
- DM model w/o producing huge continuum gamma?

→ Constraint from continuum gamma is important.

- Most models predict sizable Zγ fraction

→ Double gamma-ray line (114GeV&130GeV) ?

$$E_\gamma = m_\chi,\ m_\chi - \frac{m_Z^2}{4m_\chi}$$

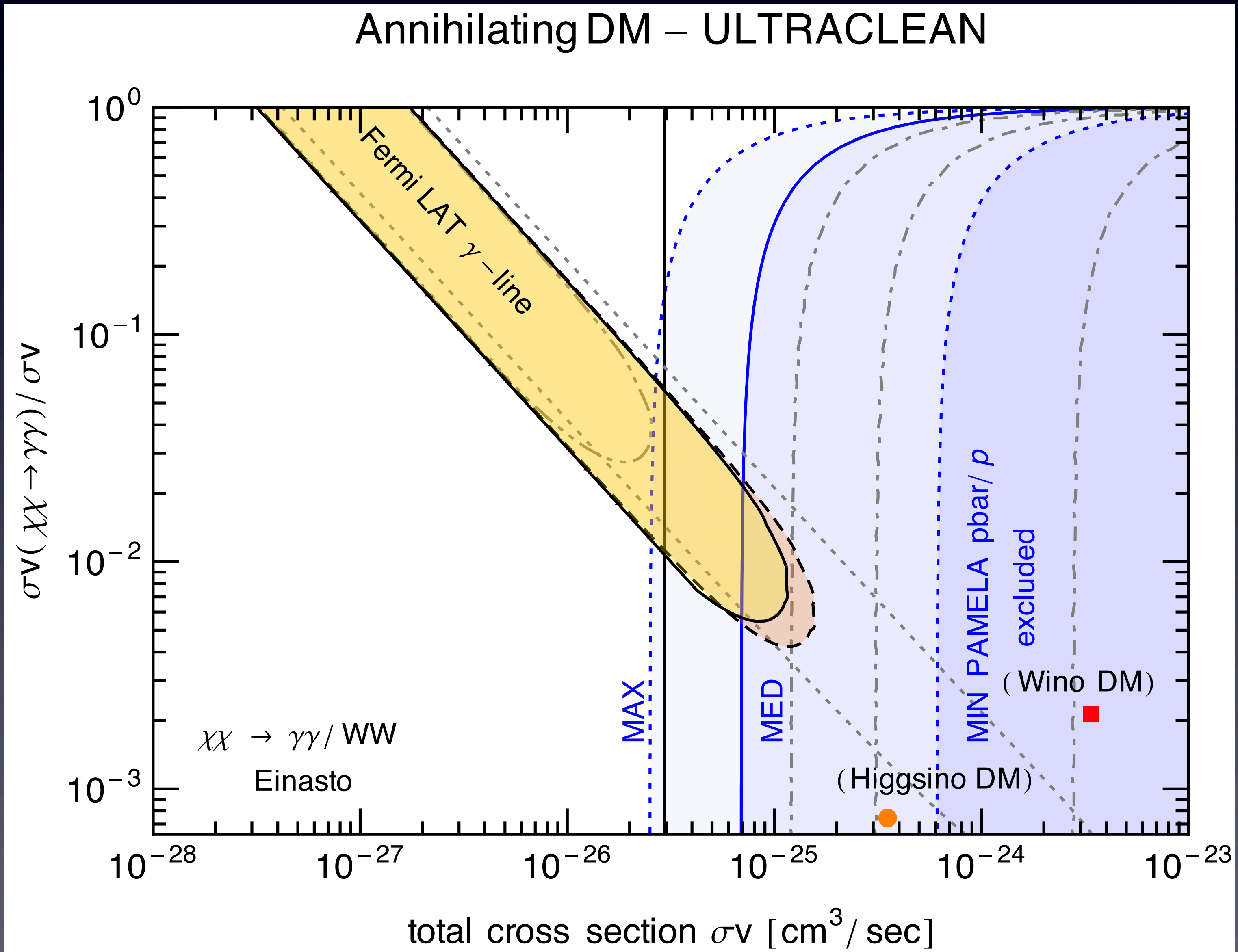
J.Cline, 1205.2688

- W.Buchmuller, M.Garny, 1206.7056

  Typical DM : $\chi + \chi \to W^+W^-, b\bar{b}, \cdots \to \text{continuum } \gamma$ dominant

  $\chi + \chi \to 2\gamma$ subdominant

- Severe constraint from continuum gamma and anti-p.
- Similar conclusion for decaying DM
- Higgsino/Wino is not suitable.

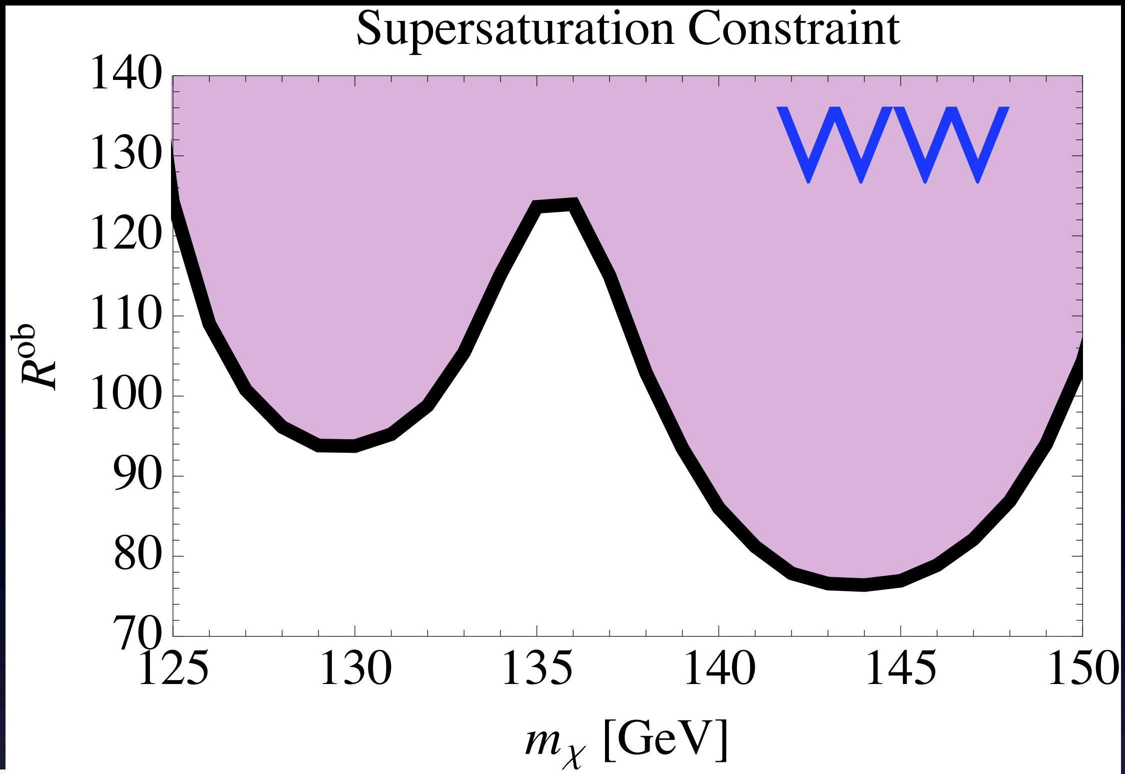


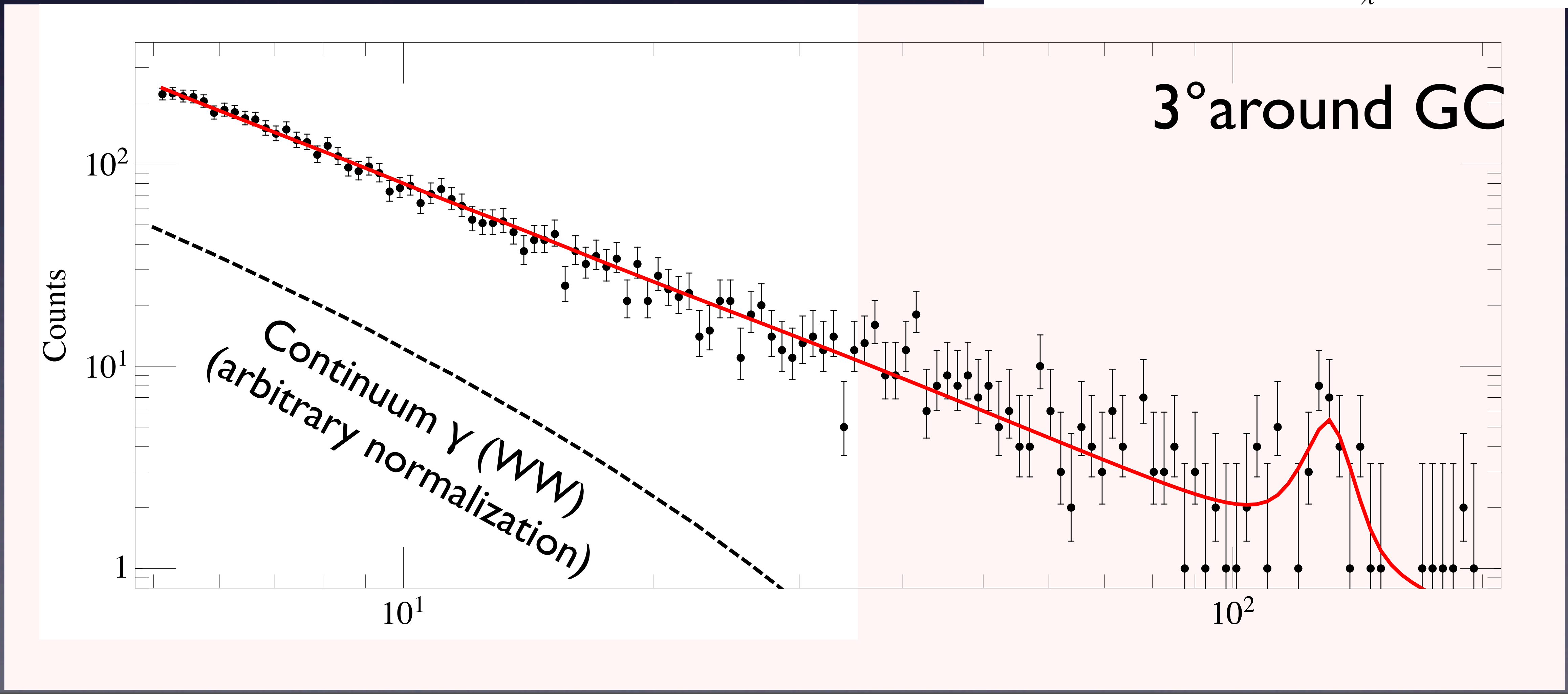
- Cohen, Lisanti, Slatyer, Wacker, 1207.0800

Upper bound on continuum gamma from DM annihilation.

$$R = \frac{\sigma_{\rm ann}}{2\sigma_{2\gamma} + \sigma_{Z\gamma}} < \sim 100$$

cf. $R \gtrsim 200$ for neutralino DM

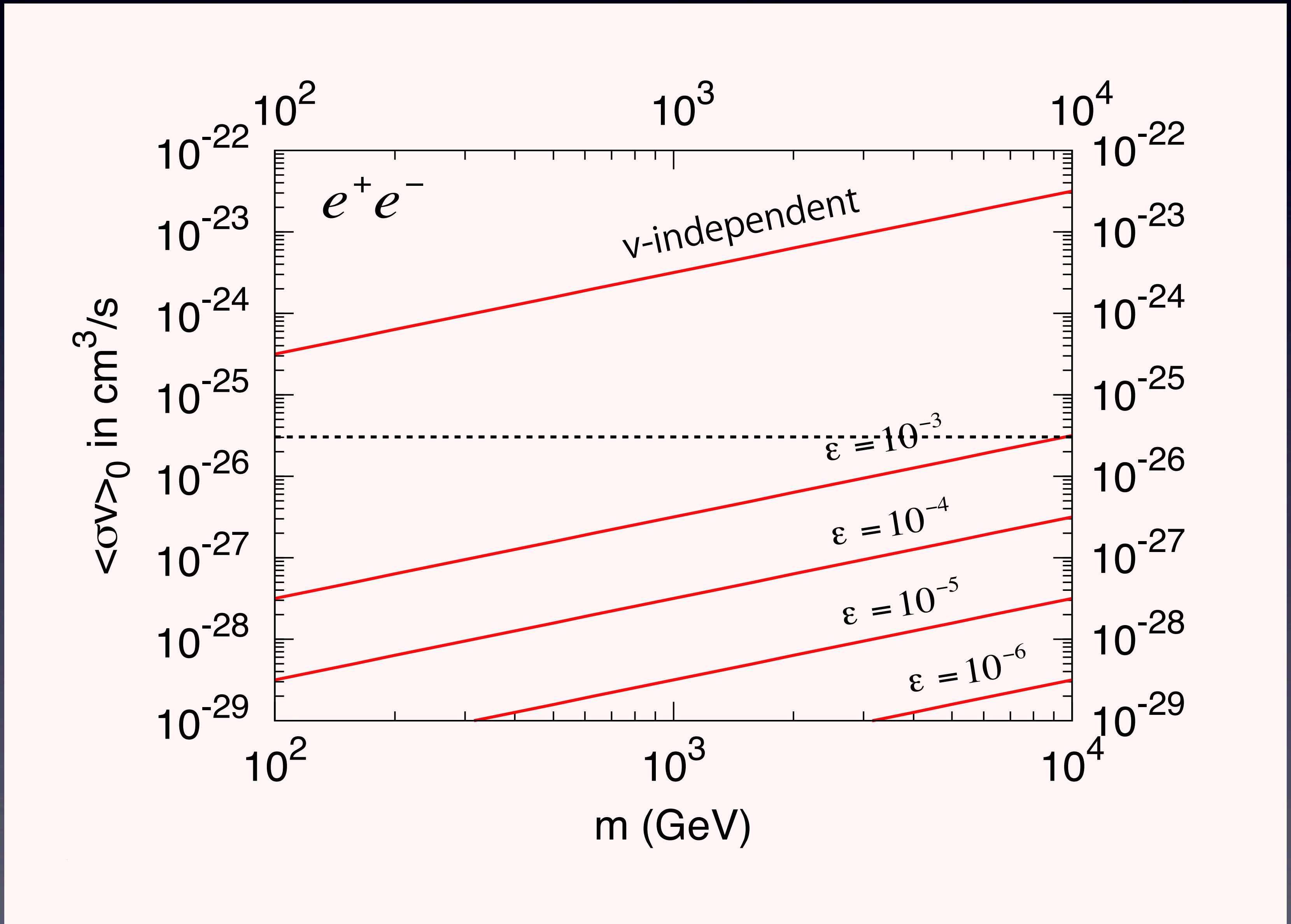




- Constraint from CMB

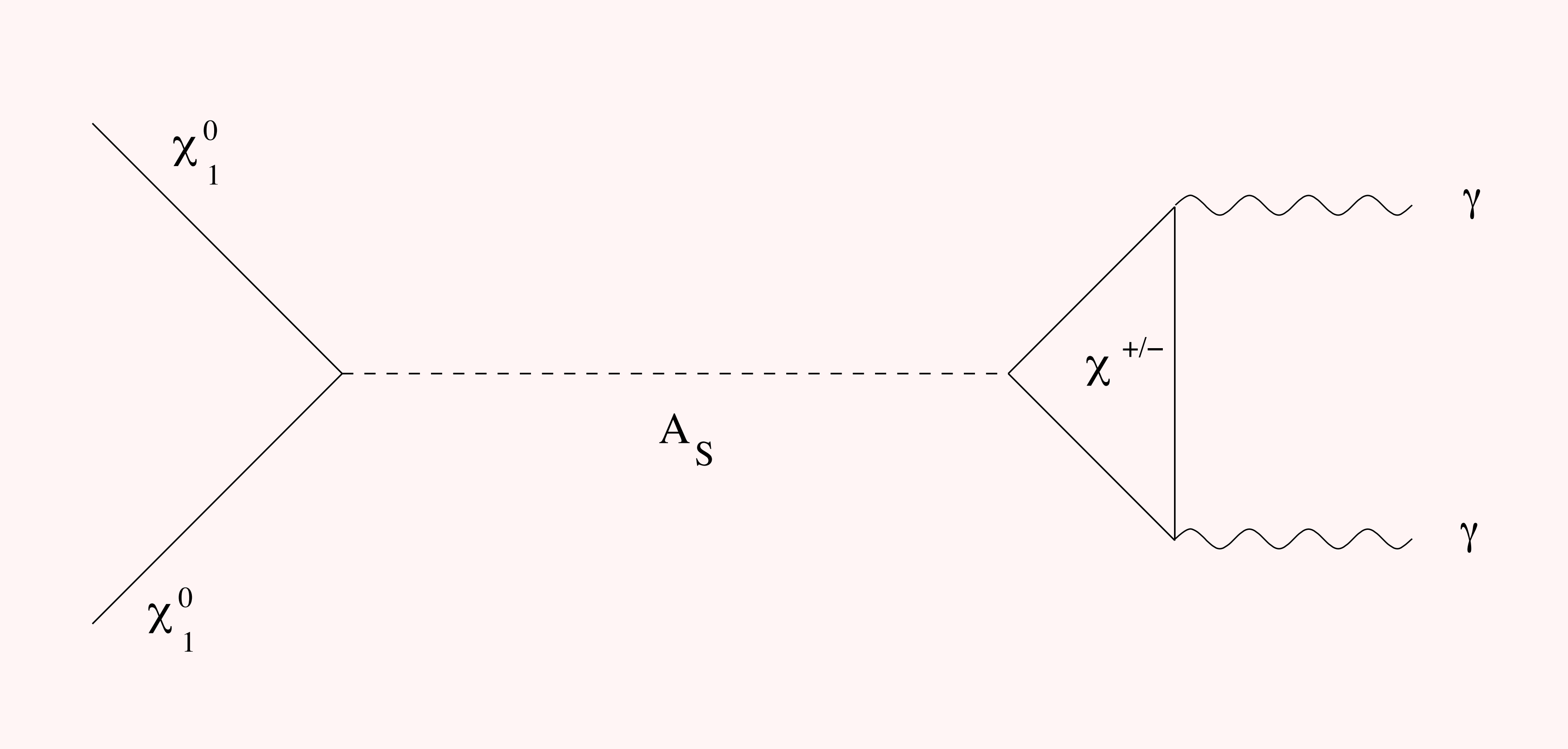
DM annihilation at recombination epoch

⟶ Ionize H ⟶ effects on CMB anisotropy



Hisano, Kawasaki, Kohri, Moroi, KN, Sekiguchi, 1102.4658

- Das, Ellwanger, Mitropoulos, 1206.2639
  - NMSSM is natural framework for solving the mu-problem in MSSM.
  - It can explain 125GeV Higgs boson found at LHC.
  - Neutralino DM in NMSSM annihilates through singlet-like CP-odd Higgs can explain 130GeV gamma.



$$W = \lambda S H_u H_d + \frac{\kappa}{3} S^3$$
$$-\mathcal{L} = m_S^2 |S|^2 + \left(\lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 + \mathrm{h.c.}\right)$$
$$+|\lambda H_u H_d + \kappa S^2|^2 + |\lambda S|^2 (|H_u|^2 + |H_d|^2)$$

- Mass of As is ~ 260GeV to enhance 2gamma.

$$\longrightarrow \quad m_{A_s}^2 \simeq -3\kappa S A_\kappa \sim (260\mathrm{GeV})^2$$

- Mixing of As and Hu, Hd are small. (Otherwise, As decays into SM quarks)

$$\longrightarrow \quad \lambda(A_\lambda - 2\kappa S) \sim 0$$

- Lightest Higgs boson is 126GeV. $\longrightarrow$ $\lambda \sim 0.6$, $\tan\beta \sim O(1)$
- Correct thermal relic abundance

$\longrightarrow$ LSP is the bino with sizable mixing with higgsino

Sample point

Parameters	
λ	0.61
κ	0.328
A_λ	267
A_κ	-114.1
$\tan\beta$	1.8
$\mu_{\rm eff}$	269
M_1	150
left-h. slepton masses	150
right-h. slepton masses	160
$A_e = A_\mu = A_\tau$	500

Sparticle masses	
$m_{\tilde{g}}$	971
$\langle m_{\tilde{q}} \rangle$	1530
$m_{\tilde{t}_1}$	204
$m_{\tilde{t}_2}$	1034
$m_{\tilde{b}_1}$	1005
$m_{\tilde{\mu}_L}$	154
$M_{\chi_1^0}$	129.6
$M_{\chi_2^0}$	217
$M_{\chi_3^0}$	287
$M_{\chi_4^0}$	309
$M_{\chi_5^0}$	376
$M_{\chi_1^\pm}$	210
$M_{\chi_2^\pm}$	370

Higgs masses	
$M_{H_1} (= M_{H_{SM}})$	124.3
M_{H_2}	256
M_{H_3}	519
$M_{A_1} (= M_{A_S})$	258.9
$R^{bb}_{A_S}$	3×10^{-3}
M_{A_2}	515
$M_{H^\pm}$	511

Components of χ_1^0	
N_{11}^2	0.826
N_{12}^2	0.026
N_{13}^2	0.077
N_{14}^2	0.065
N_{15}^2	0.009

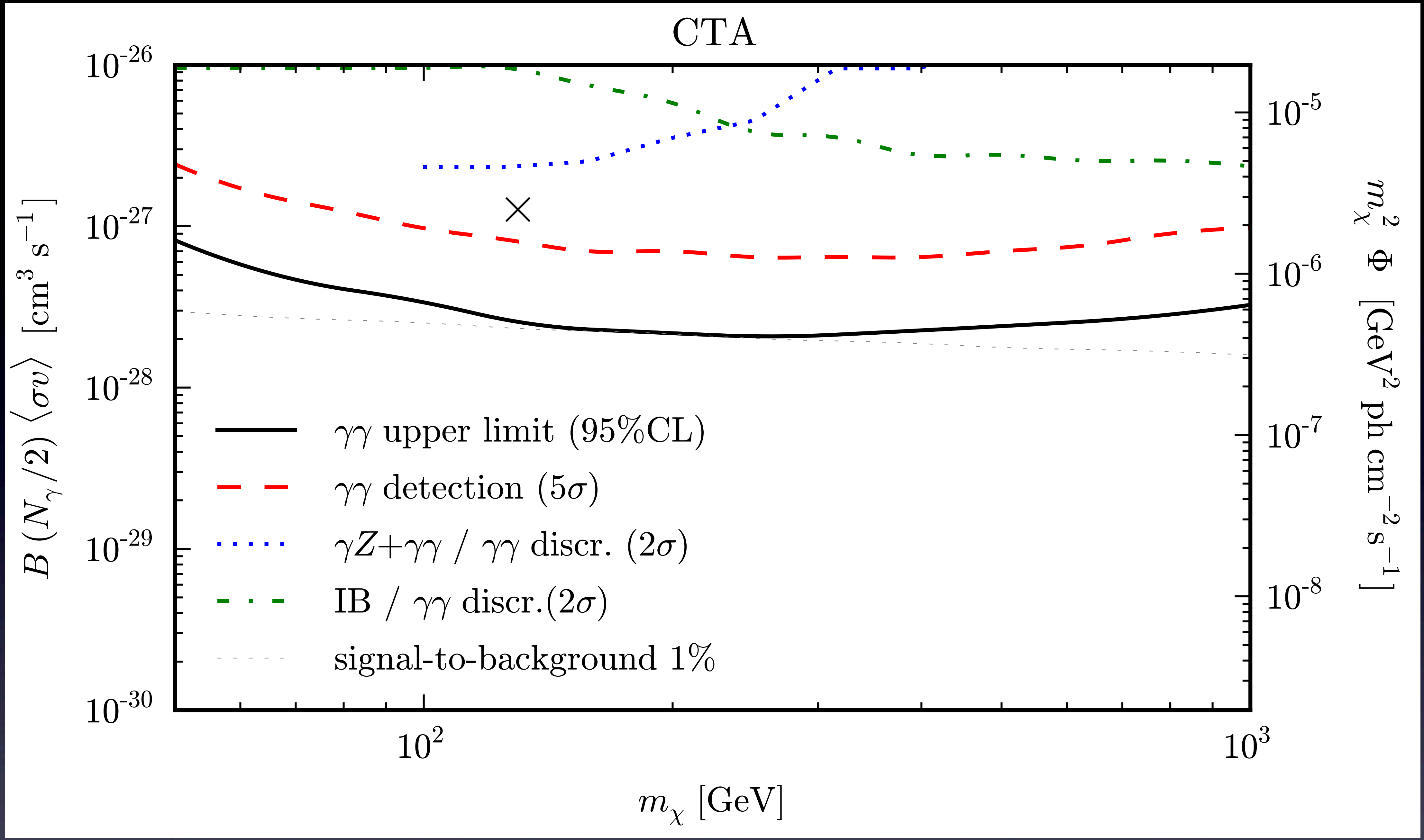
Observables	
Ωh^2	0.11
$\sigma(p)_{SI}$ $[10^{-8}$ pb$]$	1.21
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to \gamma\gamma)$ $[10^{-27}$cm^3 s$^{-1}]$	1.1
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to Z\gamma)$ $[10^{-27}$cm^3 s$^{-1}]$	0.8
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to WW)$ $[10^{-27}$cm^3 s$^{-1}]$	3.46
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to ZZ)$ $[10^{-27}$cm^3 s$^{-1}]$	0.26
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to b\bar{b})$ $[10^{-27}$cm^3 s$^{-1}]$	0.60
$\langle\sigma v\rangle(\chi_1^0\chi_1^0 \to \tau\bar{\tau})$ $[10^{-27}$cm^3 s$^{-1}]$	0.09
Δa_μ $[10^{-10}]$	6.5 ± 3.0

Future prospects

- Bergstrom, Conrad, Farnier, Bertone, Weniger, 1207.6773
  - Future prospects for confirming 130GeV line at HESS-II, CTA, GAMMA-400
  - Large area, large statistics ⟶ CTA
    Better energy resolution ⟶ GAMMA-400

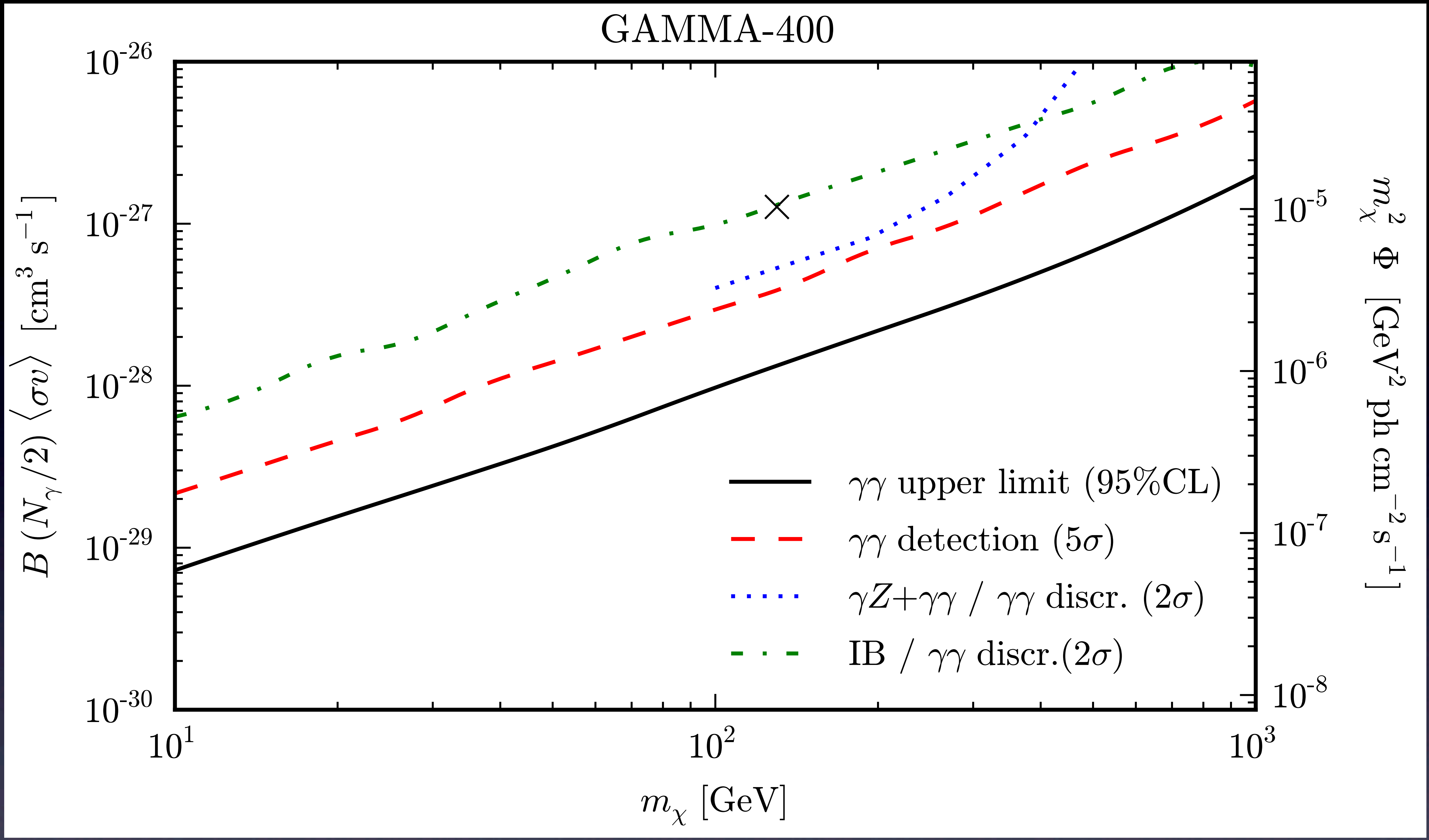
arXiv:1201.2490

	SPACED-BASED					GROUND-BASED			
	EGRET	AGILE	Fermi	CALET	**GAMMA-400**	H.E.S.S.	MAGIC	VERITAS	CTA
Energy range, GeV	0.03-30	0.03-50	0.1-300	10-10000	**0.1-3000**	>100	>50	>100	>10
Angular resolution, deg (E_γ > 100 GeV)	0.2 $E_\gamma \sim$ 0.5 GeV	0.1 $E_\gamma \sim$ 1 GeV	0.1	0.1	**~0.01**	0.1	0.1	0.1	0.1
Energy resolution, % (E_γ > 100 GeV)	15 $E_\gamma \sim$ 0.5 GeV	50 $E_\gamma \sim$ 1 GeV	10	2	**~1**	15	20	15	15



Signal region : 2° around GC, 5 hours observation

- CTA can confirm/exclude gamma excess
- γγ/γZ discrimination is difficult



Signal region : 20° around GC, ~1 year observation

- GAMMA-400 can confirm/exclude gamma excess
- γγ/γZ discrimination may be possible

Summary

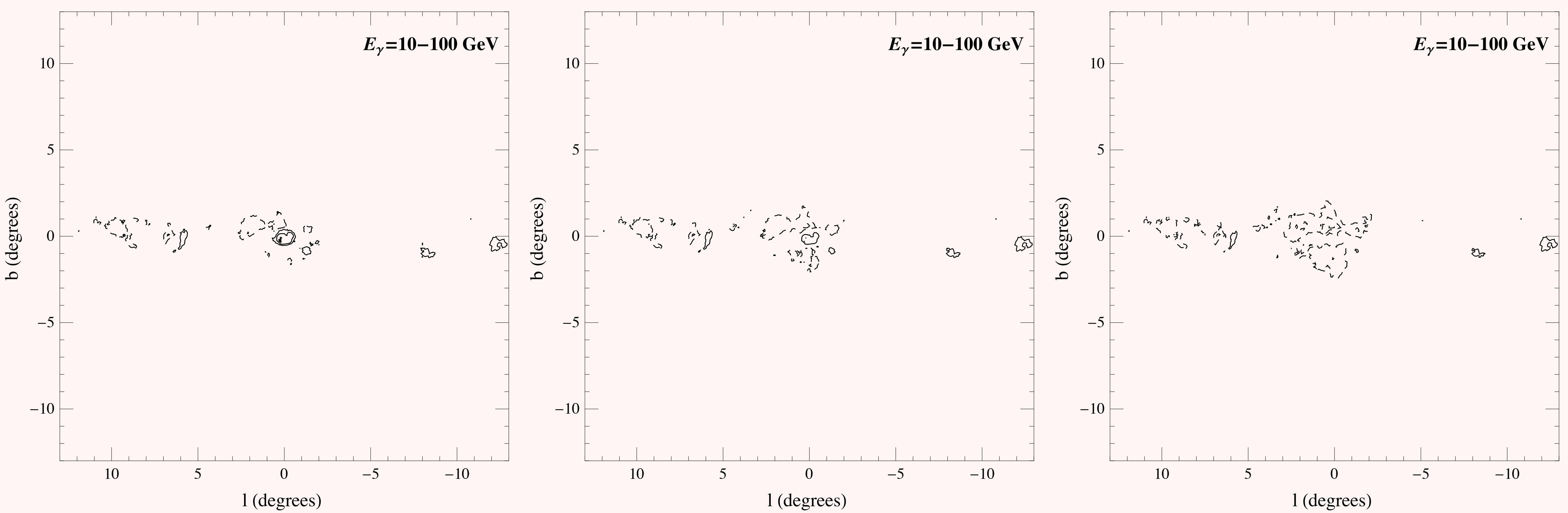
- There are increasing evidence of 130GeV gamma line from Galactic center.
- Not likely correlated with Fermi bubble.
- It may be explained by dark matter annihilation or some astrophysical processes.
- CTA will be able to confirm/exclude it.

Backup slides

- Hooper, Kelso, Queiroz, 1209.3105

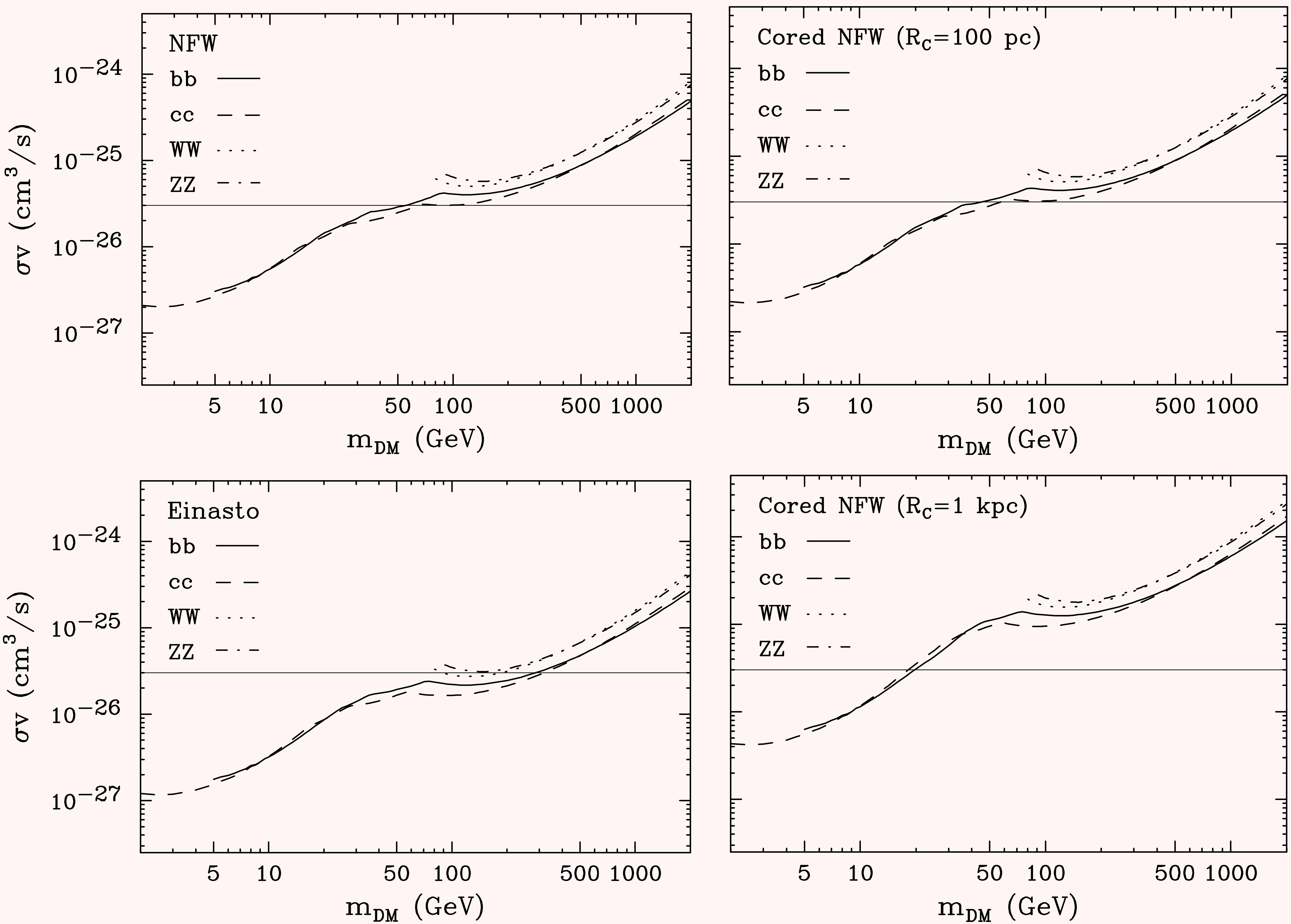
  “robust constraint” on DM from GC region

Subtract DM contribution with increasing cross section →

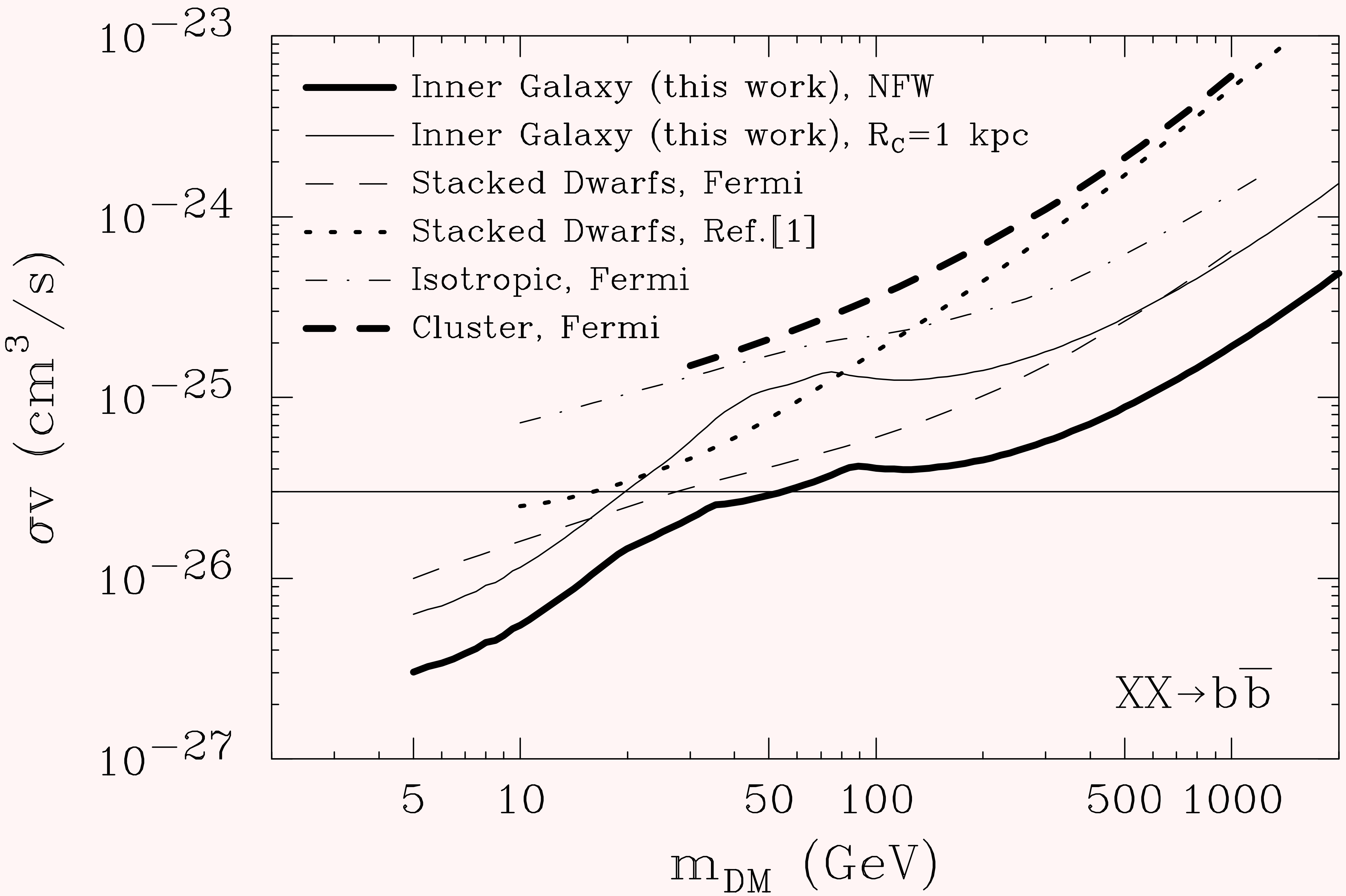


(NFW profile)

Dashed : over subtracted


NFW
bb
cc
WW
ZZ
Cored NFW (R_C=100 pc)
Einasto
Cored NFW (R_C=1 kpc)
σv (cm^3/s)
10^{-24}
10^{-25}
10^{-26}
10^{-27}
5
10
50
100
500
1000
m_{DM} (GeV)

Comparison with other regions



- Frandsen et al., 1207.3971

Prediction on DM direct detection from loop-induced interaction

real scalar DM :

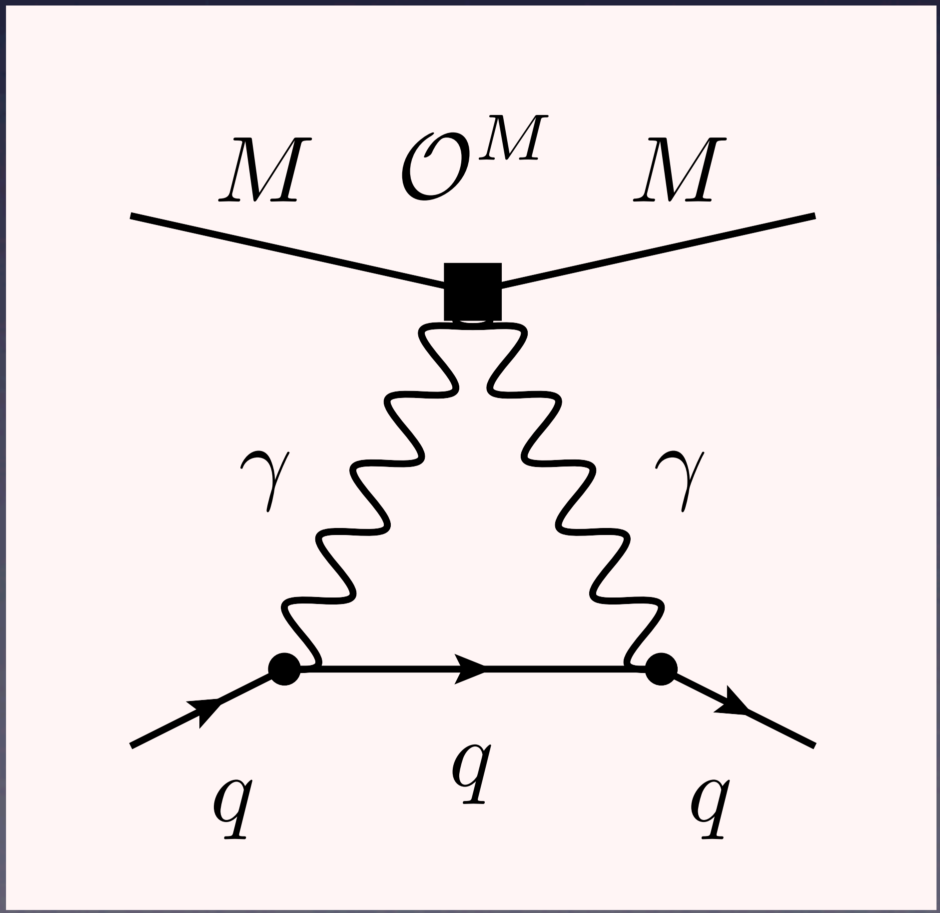
$$\mathcal{L}_{\rm eff} = c\chi^2 F_{\mu\nu}F^{\mu\nu}\,, c\chi^2 F_{\mu\nu}\tilde{F}^{\mu\nu}$$

fermionic DM :

$$\mathcal{L}_{\rm eff} = c\bar{\chi}\chi F_{\mu\nu}F^{\mu\nu}\,, c\bar{\chi}\chi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$, c\bar{\chi}\gamma_5\chi F_{\mu\nu}F^{\mu\nu}, c\bar{\chi}\gamma_5\chi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$, c\bar{\chi}\sigma^{\mu\nu}\chi F^{\rho}_{\mu}\tilde{F}_{\nu\rho}$$ (Dirac)



Majorana fermion DM

$$\mathcal{L}_{\rm eff} = c\bar{\chi}\chi F_{\mu\nu}F^{\mu\nu}$$

XENON100

Fermi-LAT

XENON1T

- Cholis, Tavakoli, Ullio, 1207.1468
  - Upper bound on continuum gamma from DM annihilation.
  - Similar conclusion to Cohen et al.