Decaying DM & Fermi 130 GeV γ-ray line

B. Kyae & JCP, arXiv: 1205.4151
JCP & S. C. Park, arXiv: 1207.4981

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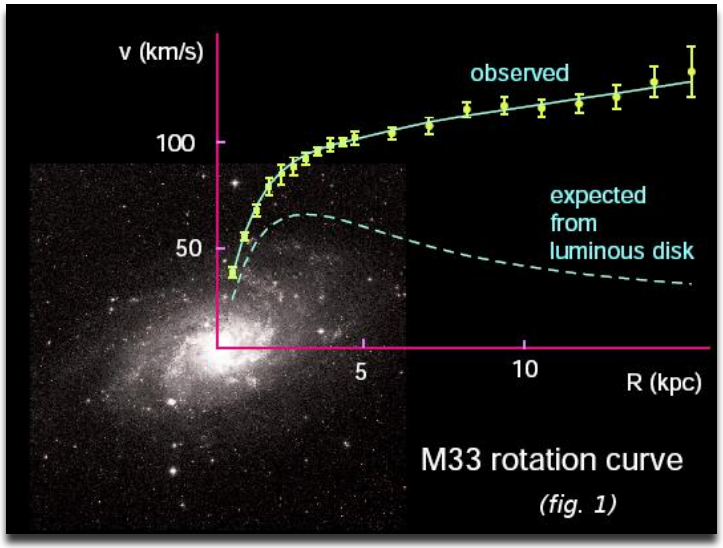
Outline

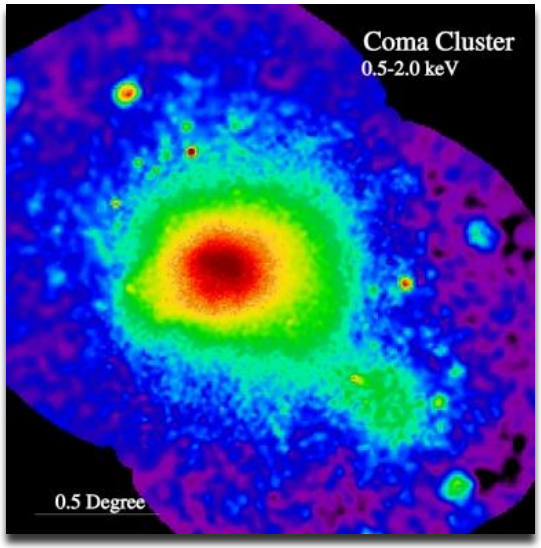
- Why dark matter? ⟶ Covered by other speakers!
- 130 GeV line from the Fermi data ⟶ Weniger's talk
- 130 GeV line from DM?
  - ❖ Annihilation
  - ❖ Decay
- Conclusion

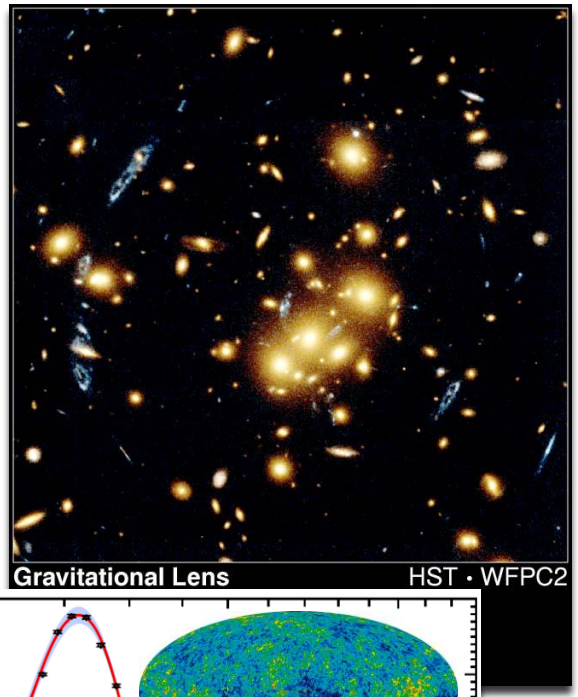
Dark matter

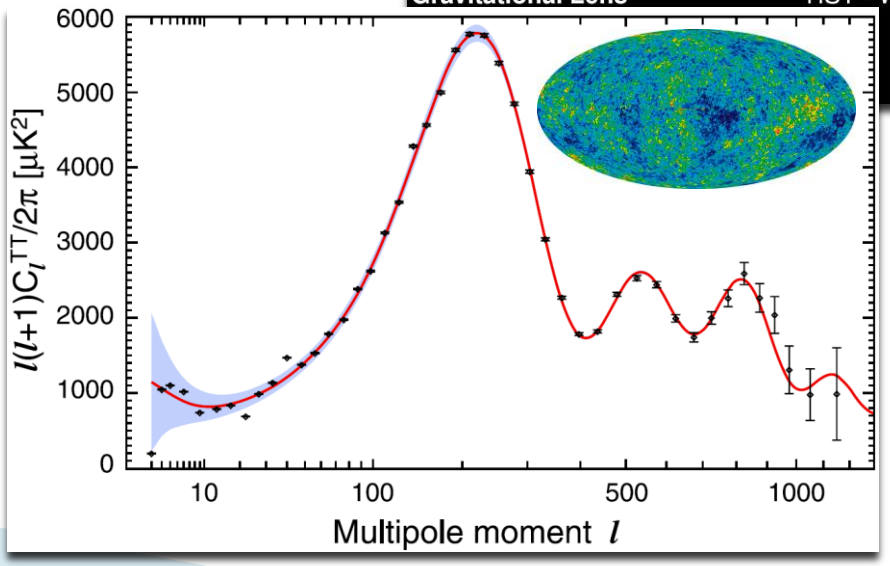
- discovered via gravity

  by Fritz Zwicky (1933) & Vera Rubin (1970)



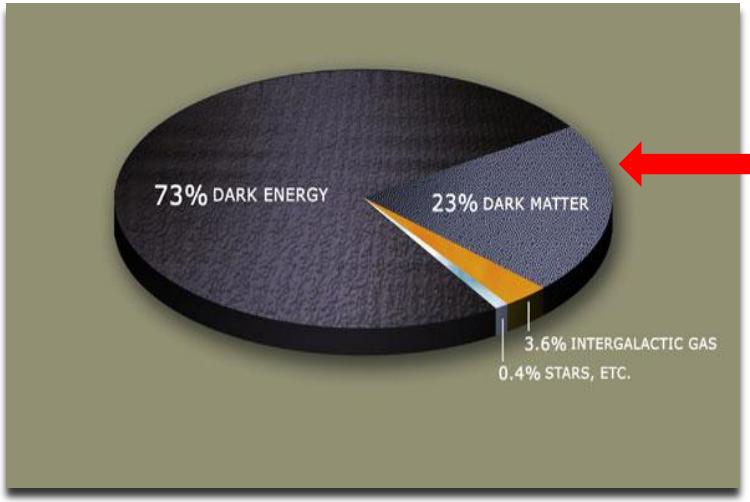


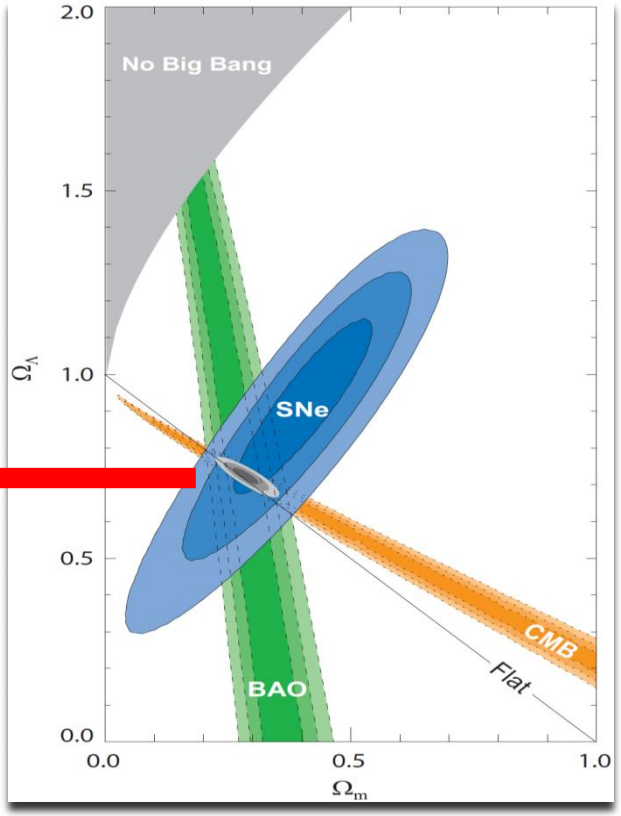




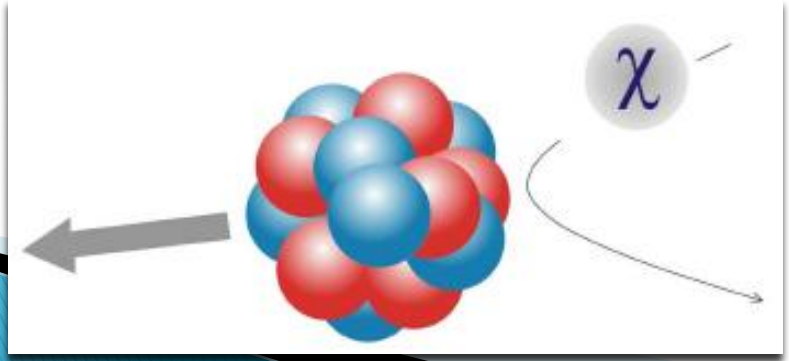
And …

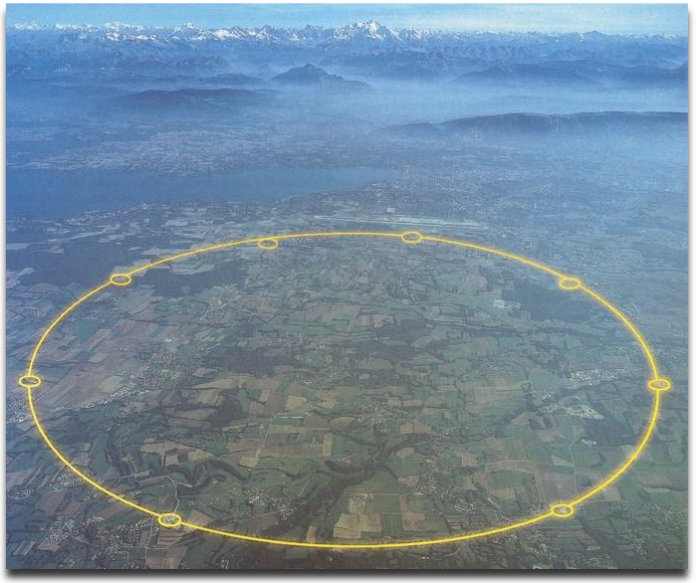
- DM accounts for 23% of the total mass-energy of the Universe.





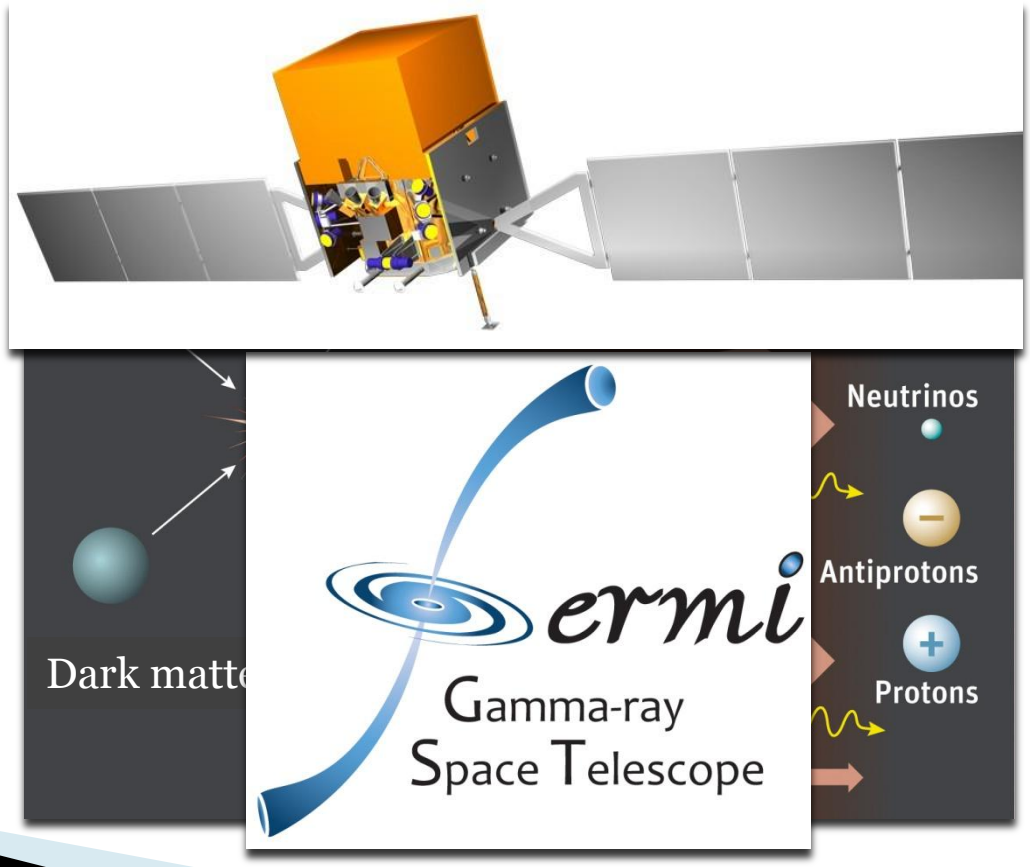
- For the particle identification, a discovery via EM, strong or weak probes is needed: e.g. DM direct detection, production, etc.





Indirect detection

- Indirect detection experiments search for the products of DM annihilation or decay: gamma rays, neutrinos, positrons or antiprotons
- Not conclusive evidence since the backgrounds from other sources are not fully understood.



Importance of γ-rays

- γ-rays propagate unperturbed and preserve spatial information about their sources. (cf. $e^{\pm}$, $p^{\pm}$, …)
- Efficient S/B discrimination in searches for γ-ray signatures.
- Signatures in E_γ play a major role in DM searches. (monochromatic and/or continuous γ-rays)

New Fermi data treatment

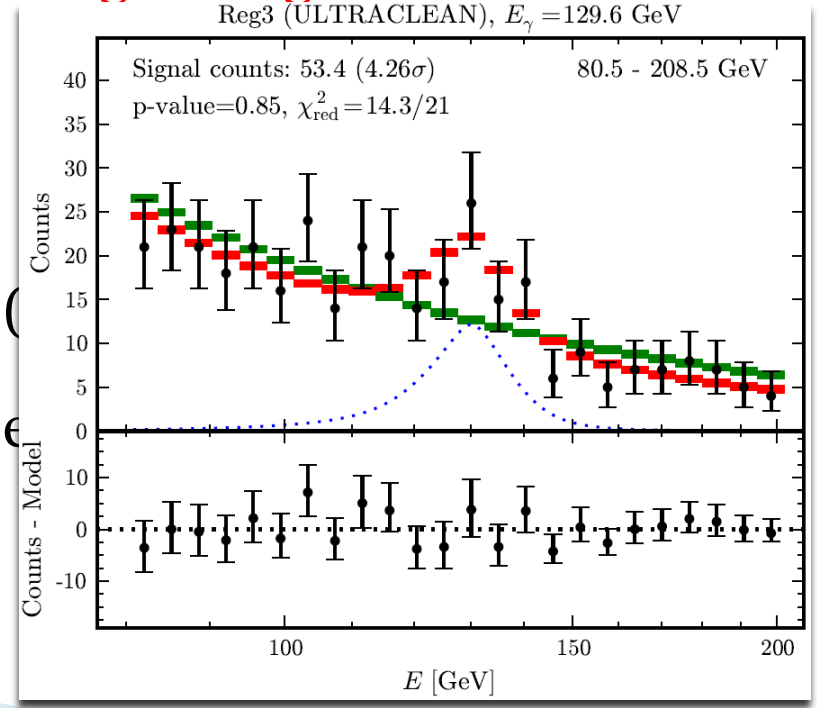
Weniger's talk

Bringmann et al, arXiv: 1203.1312
Weniger, arXiv: 1204.2797

- All data collected so far (43 month)
- Most up-to-date publicly available event selections
- New data-driven algorithm:

  ⇒ optimized target regions maximizing the signal-to-noise ratio for different DM halo profiles
- E_γ: 20-300 GeV

  E_γ<20 GeV: target region selection (
- Inefficient target region choice can e



130 GeV line from Fermi data

Weniger, arXiv: 1204.2797

- 4.6σ (3.2σ) indication for γ-ray excess at $E_\gamma \approx 130$ GeV

  (1203.1312: internal bremsstrahlung-like signal,

  m_{DM}~150GeV, 4.3σ/3.1σ)

$$\text{Einasto (NFW): } m_{\rm DM} = 129.8 \pm 2.4^{+7}_{-13}\ \text{GeV}$$
$$\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27}\ \text{cm}^3/\text{s} \quad (2.27 \pm 0.57^{+0.32}_{-0.51} \times 10^{-27}\ \text{cm}^3/\text{s})$$

- Reference DM density profiles:

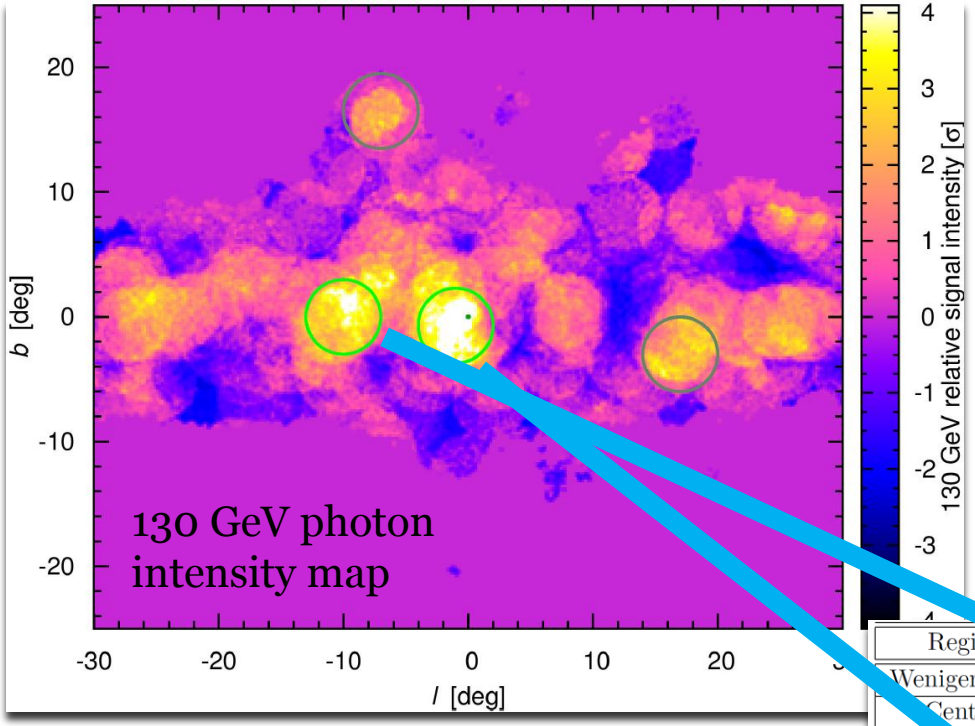
Cored isothermal $\rho_{\rm dm}(r) \propto \dfrac{1}{1+(r/r_s)^2}$

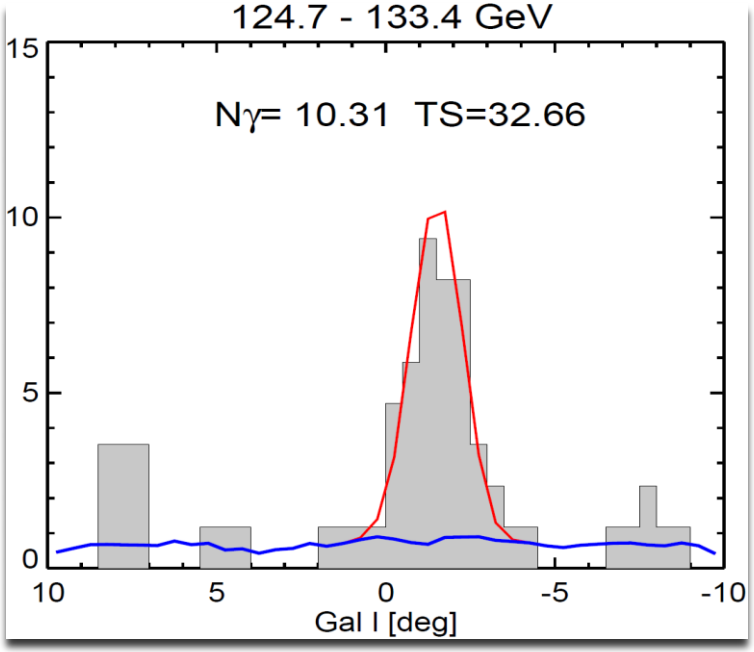
NFW (α=1) $\rho_{\rm dm}(r) \propto \dfrac{1}{(r/r_s)^{\alpha}\,(1+r/r_s)^{3-\alpha}}$

Einasto $\rho_{\rm dm}(r) \propto \exp\left(-\dfrac{2}{\alpha_E}\dfrac{r^{\alpha_E}}{r_s^{\alpha_E}}\right)$

More evidence

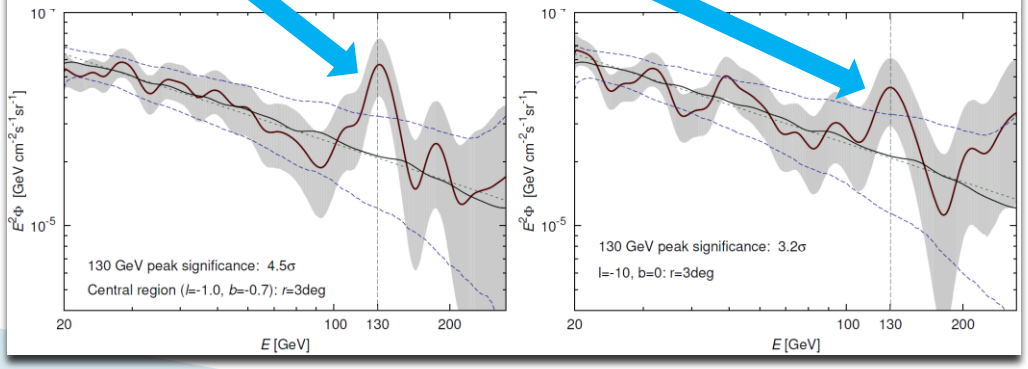
Su & Finkbeiner, arXiv:1206.1616





Tempel et al., arXiv:1205.1045

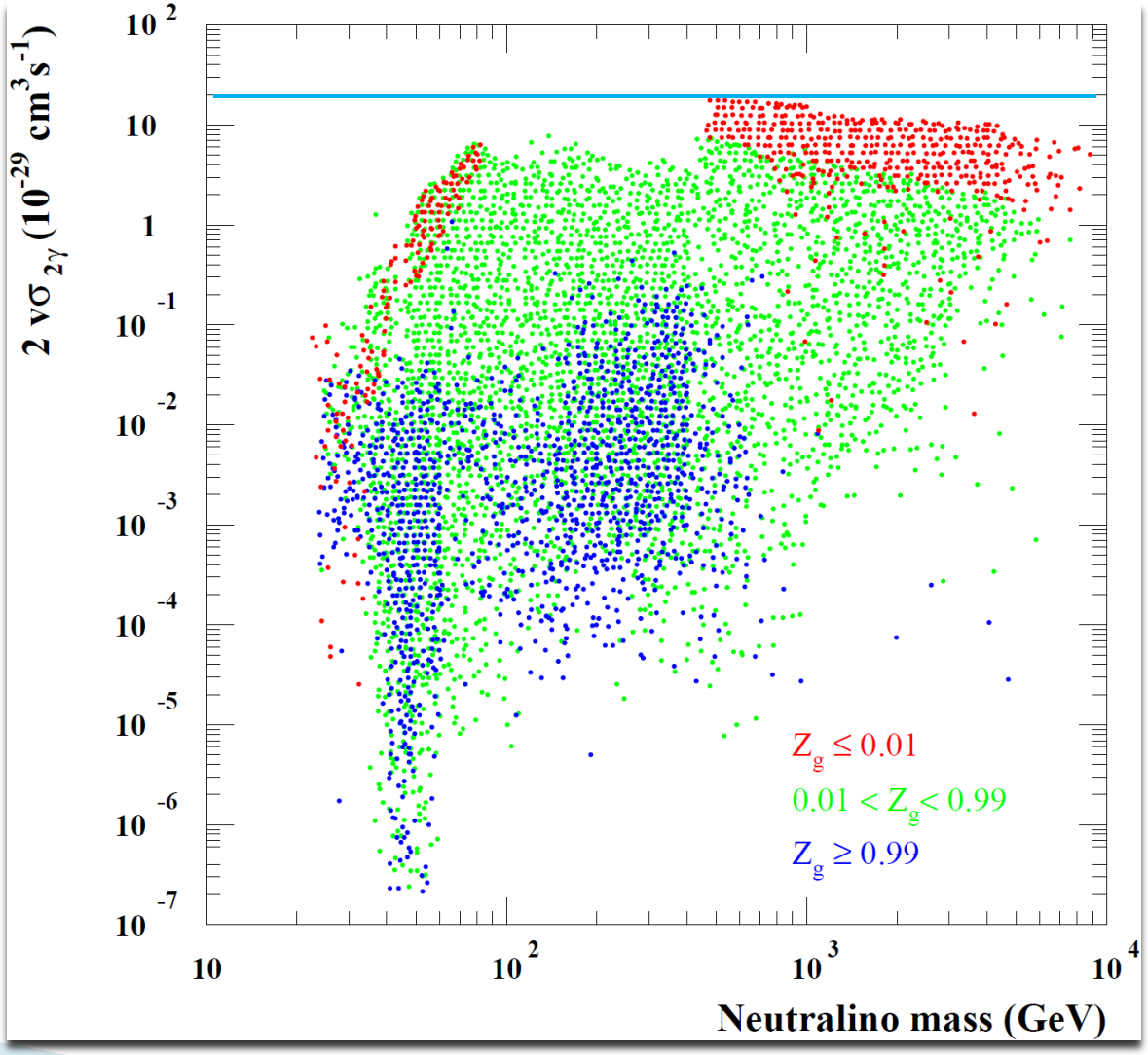
Region	l (deg)	b (deg)	N_γ (20–300) GeV	N_γ (120–140 GeV)	significance
Weniger Reg3		–	3298	65	3.6σ
Central	-1	0.7	818	27	4.5σ
[illegible]st	-10	0	726	21	3.2σ
East	17	-3	481	14	2.7σ
North	-7	16.5	[illegible]	4	1.6σ



Origin of 130 GeV γ?

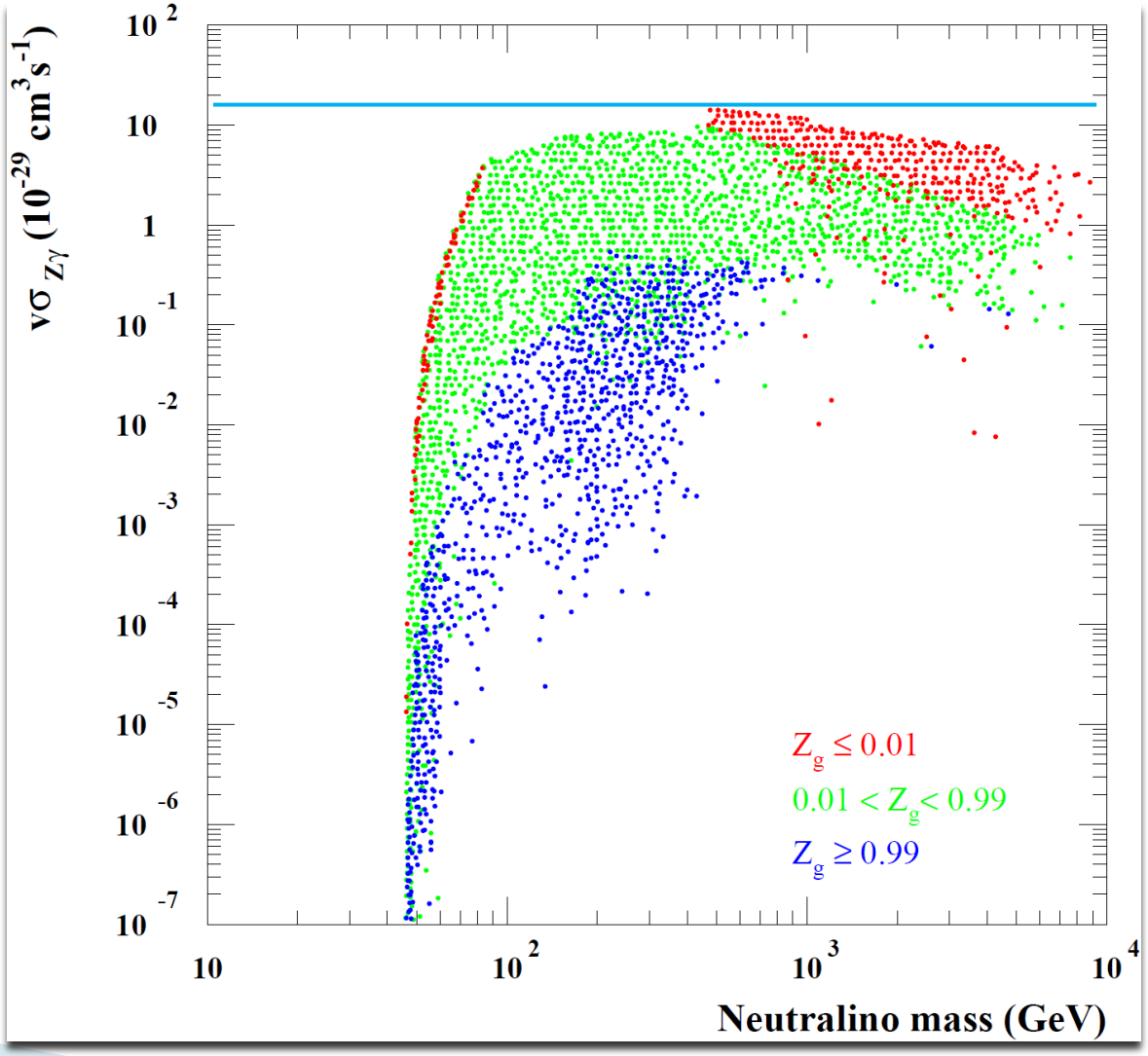
Neutralino in MSSM: 2γ

Bergstorm et al,
astro-ph/9712318



Neutralino in MSSM: Z+γ

Bergstorm et al, astro-ph/9712318



DM annihilation

B. Kyae & JCP, arXiv: 1205.4151

- DM is EM neutral

  ⇒ $\langle \sigma v \rangle_{\gamma\gamma/\gamma X}$: one-loop suppressed (not too heavy charged particles)

- $\langle \sigma v \rangle_{\gamma\gamma} \sim 2 \cdot 10^{-27}\ cm^3/s$

  ⇒ large enough new couplings or resonance

- $\langle \sigma v \rangle_{thermal} \sim 3 \cdot 10^{-26}\ cm^3/s$

  ⇒ two different interactions to separate $\langle \sigma v \rangle_{\gamma\gamma}$ from $\langle \sigma v \rangle_{thermal}$

How about DM decay?

DM decay

B. Kyae & JCP, arXiv: 1205.4151

$$\frac{d\Phi_{\rm dec}}{dE_\gamma d\Omega} = \frac{\Gamma}{4\pi} r_\odot \left(\frac{\rho_\odot}{2m_{\rm DM}}\right) \int_{\rm l.o.s.} ds \frac{1}{r_\odot} \left(\frac{\rho_{\rm halo}(r)}{\rho_\odot}\right) \frac{dN_{\rm dec}}{dE_\gamma}$$

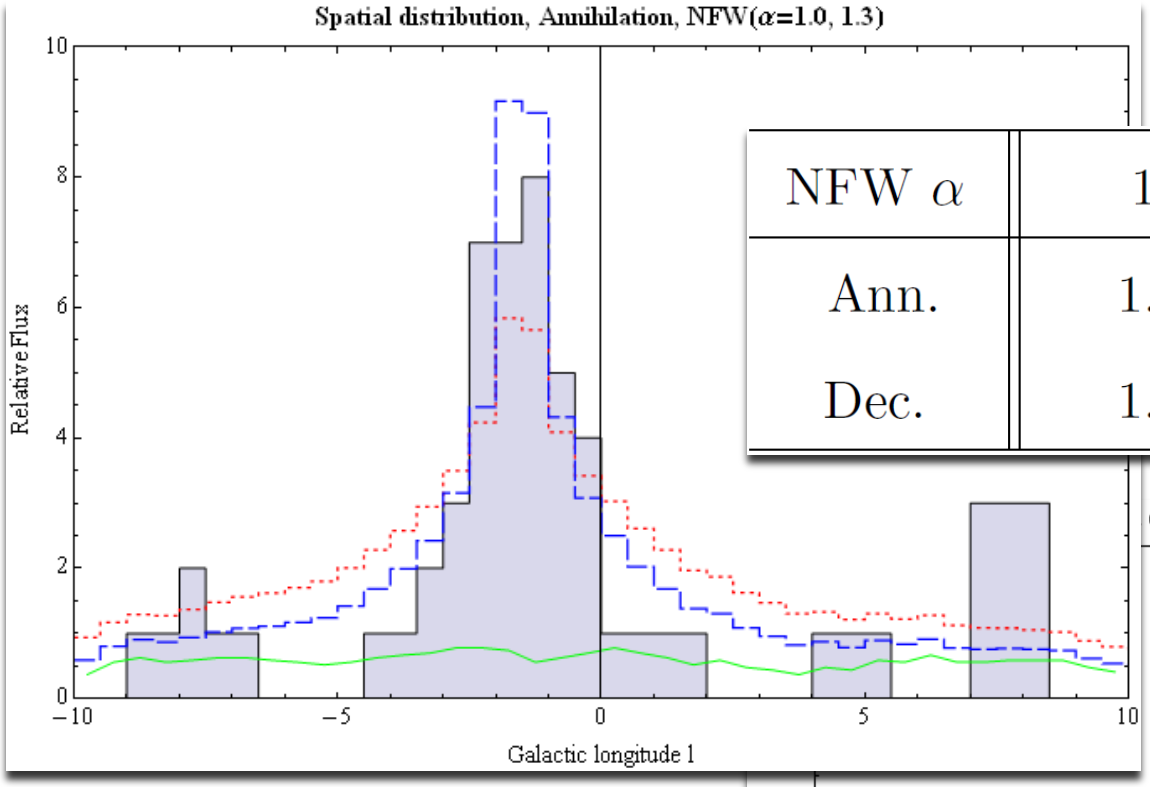
$$\frac{d\Phi_{\rm ann}}{dE_\gamma d\Omega} = \frac{\langle\sigma v\rangle}{8\pi} r_\odot \left(\frac{\rho_\odot}{m_{\rm DM}}\right)^2 \int_{\rm l.o.s.} ds \frac{1}{r_\odot} \left(\frac{\rho_{\rm halo}(r)}{\rho_\odot}\right)^2 \frac{dN_{\rm ann}}{dE_\gamma}$$

$$\Gamma^{-1} \approx \mathcal{C} \times 10^{29}\ \text{sec} \quad \mathcal{C} \in (0.1, 1)$$

- difficult to determine the detailed spatial distribution of the signal due to the small # of events

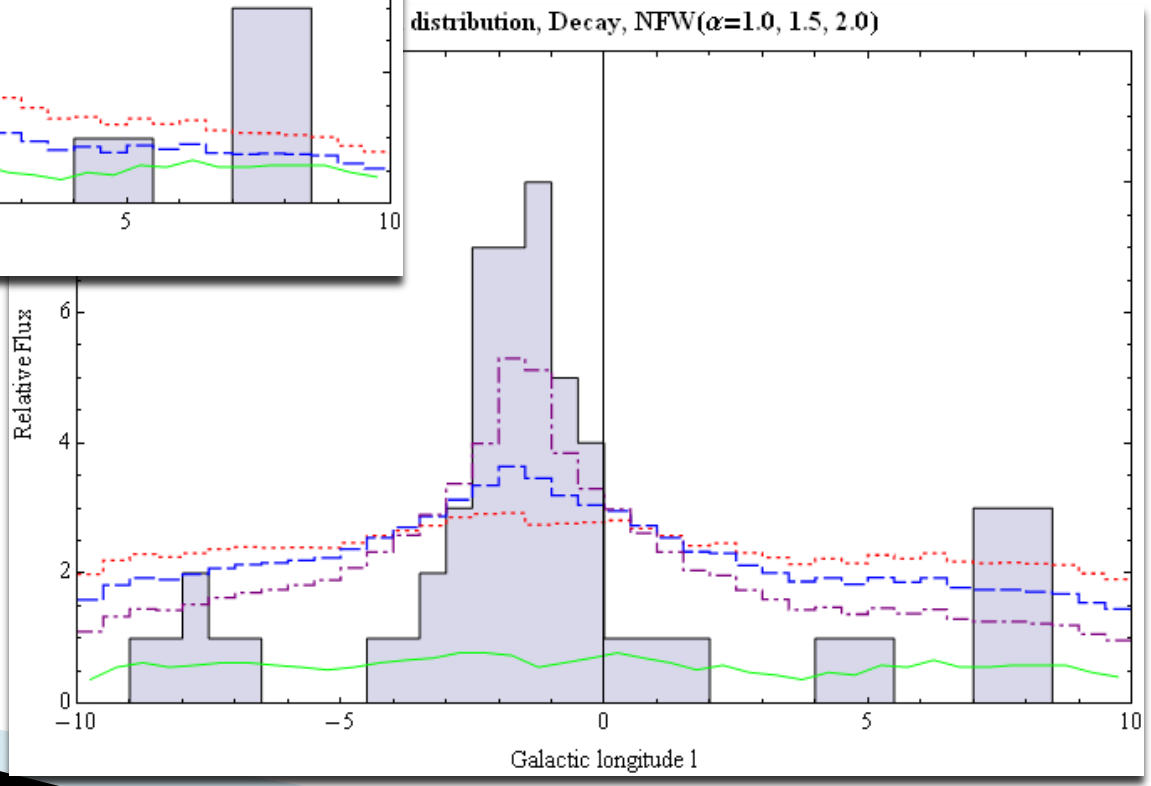
Annihilation vs Decay

JCP & S.C.Park,
arXiv: 1207.4981



χ^2/d.o.f.

NFW α	1.0	1.3	1.5	1.7
Ann.	1.05	1.03	1.17	1.40
Dec.	1.80	1.60	1.44	1.28

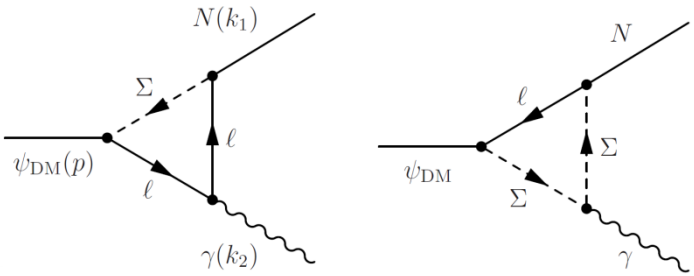


Fermionic DM decay

Garny et al, arXiv: 1011.3786,
B.Kyae & JCP, arXiv: 1205.4151

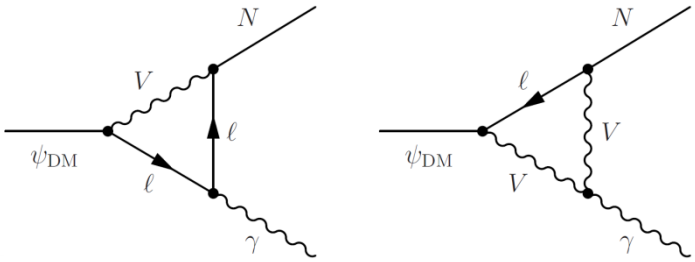
$$-\mathcal{L}_{\rm eff} = \overline{\psi}_{\rm DM}\gamma^\mu \left[g_\psi^L P_L + g_\psi^R P_R\right] l V_\mu + \overline{N}\gamma^\mu \left[g_N^L P_L + g_N^R P_R\right] l V_\mu + \overline{\psi}_{\rm DM}\left[y_\psi^L P_L + y_\psi^R P_R\right] l\Sigma + \overline{N}\left[y_N^L P_L + y_N^R P_R\right] l\Sigma \; + \; \text{h.c.},$$

- $m_V >> m_\Sigma$



$$\tau_{\psi_{\rm DM}\to\gamma N} \approx 5.9\times 10^{28}\ \text{sec.}\ \frac{0.1}{[\sum_l (y_N^L y_\psi^L - \eta y_N^R y_\psi^R)]^2}\left(\frac{260\ \text{GeV}}{m_{\psi_{\rm DM}}}\right)^5\left(\frac{m_\Sigma}{10^{14}\ \text{GeV}}\right)^4$$

- $m_V << m_\Sigma$



$$\tau_{\psi_{\rm DM}\to\gamma N} \approx 1.7\times 10^{27}\ \text{sec.}\ \frac{0.1}{[\sum_l (\eta g_N^L g_\psi^L - g_N^R g_\psi^R)]^2}\left(\frac{260\ \text{GeV}}{m_{\psi_{\rm DM}}}\right)^5\left(\frac{m_V}{10^{14}\ \text{GeV}}\right)^4$$

Scalar DM decay

- $c_5 \frac{\phi}{\Lambda} F^{\mu\nu} F_{\mu\nu}$ should be extremely suppressed for $\Gamma^{-1} \sim 10^{28\text{-}29}$ s.

  : $\Lambda >> M_{pl}$ or $c_5 << 1$

B.Kyae & JCP, arXiv: 1205.4151

1. D6 Op. (B. Kyae & JCP:1205.4151, Kang et al: 1206.2863)

2. D5 Op. w/ additional suppressions (JCP & S. C. Park: 1207.4981)

Scalar DM via D6 Op.

B.Kyae & JCP, arXiv: 1205.4151

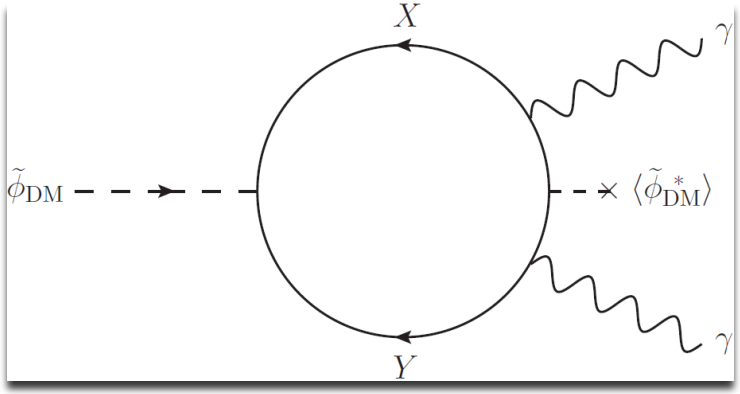
$$-\mathcal{L}_{\rm eff} = c_{\rm eff}\frac{\tilde{\phi}^*_{\rm DM}\tilde{\phi}_{\rm DM}}{M_*^2}F_{\mu\nu}F^{\mu\nu}$$

$\tilde{\varphi}$ develop a VEV

$$\Gamma_{\tilde{\phi}_{\rm DM}\to\gamma\gamma} \approx \frac{c_{\rm eff}^2}{4\pi}\left(\frac{\langle\tilde{\phi}_{\rm DM}\rangle}{M_*^2}\right)^2 m^3_{\tilde{\phi}_{\rm DM}}$$

$$\approx 0.85\times 10^{-29}\ \text{sec.}^{-1}\left(\frac{c_{\rm eff}\langle\tilde{\phi}_{\rm DM}\rangle}{200\ \text{GeV}}\right)^2\left(\frac{10^{16}\ \text{GeV}}{M_*}\right)^4\left(\frac{m_{\tilde{\phi}_{\rm DM}}}{260\ \text{GeV}}\right)^3$$

$$W_{\gamma\gamma} = \lambda_{\gamma\gamma}\Phi XY + M_X XX^c + M_Y YY^c$$

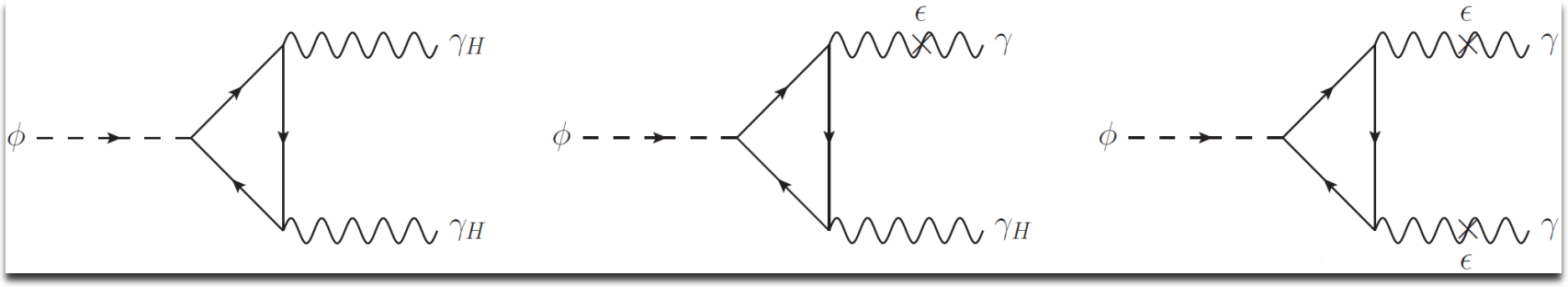


Scalar DM via D5 Op.

JCP & S.C.Park,
arXiv: 1207.4981

$$\mathcal{O} = c_5 \frac{\phi}{\Lambda}\left(F'_{\mu\nu}F'^{\mu\nu} + \epsilon F_{\mu\nu}F'^{\mu\nu} + \epsilon^2 F_{\mu\nu}F^{\mu\nu}\right)$$

$$\Gamma(\phi \to \gamma_H\gamma_H) : \Gamma(\phi \to \gamma\gamma_H) : \Gamma(\phi \to \gamma\gamma) \simeq 1 : \epsilon^2 : \epsilon^4$$



$$\mathcal{L}_{SM} - \frac{1}{4}\hat{F}_{H\mu\nu}\hat{F}_H^{\mu\nu} - \frac{\sin\epsilon}{2}\hat{F}_{\mu\nu}\hat{F}_H^{\mu\nu} - \lambda\phi\overline{\psi}\psi + i\overline{\psi}\gamma^\mu(\partial_\mu - i\hat{g}_H\hat{A}_\mu^H)\psi - m_\psi\overline{\psi}\psi$$

$$\Gamma(\phi \to \gamma_H\gamma_H) = \frac{(\alpha_H\lambda)^2}{256\pi^3}\frac{m_\phi^3}{m_\psi^2}|F(\tau)|^2$$

$$F(\tau = 4m_\psi^2/m_\phi^2) = -2\tau\left[1 + (1-\tau)\arcsin^2(1/\sqrt{\tau})\right]$$

Scalar DM via D5 Op. 2

JCP & S.C.Park,
arXiv: 1207.4981

- Longevity of φ: $\Gamma(\phi \to \gamma_H \gamma_H)^{-1} \gg \tau_{\rm Universe} \approx 4.34 \times 10^{17}\,{\rm sec}$

$$\Rightarrow \quad \alpha_H \lambda \ll 1.96 \times 10^{-7} \left(\frac{m_\psi}{10^{16}\,{\rm GeV}}\right) \quad \text{for} \quad m_\phi = 260{\rm GeV}$$

- 130 GeV line: $\Gamma^{-1} \approx \mathcal{C} \times 10^{29}$ sec with $\mathcal{C} \in (0.1, 1)$

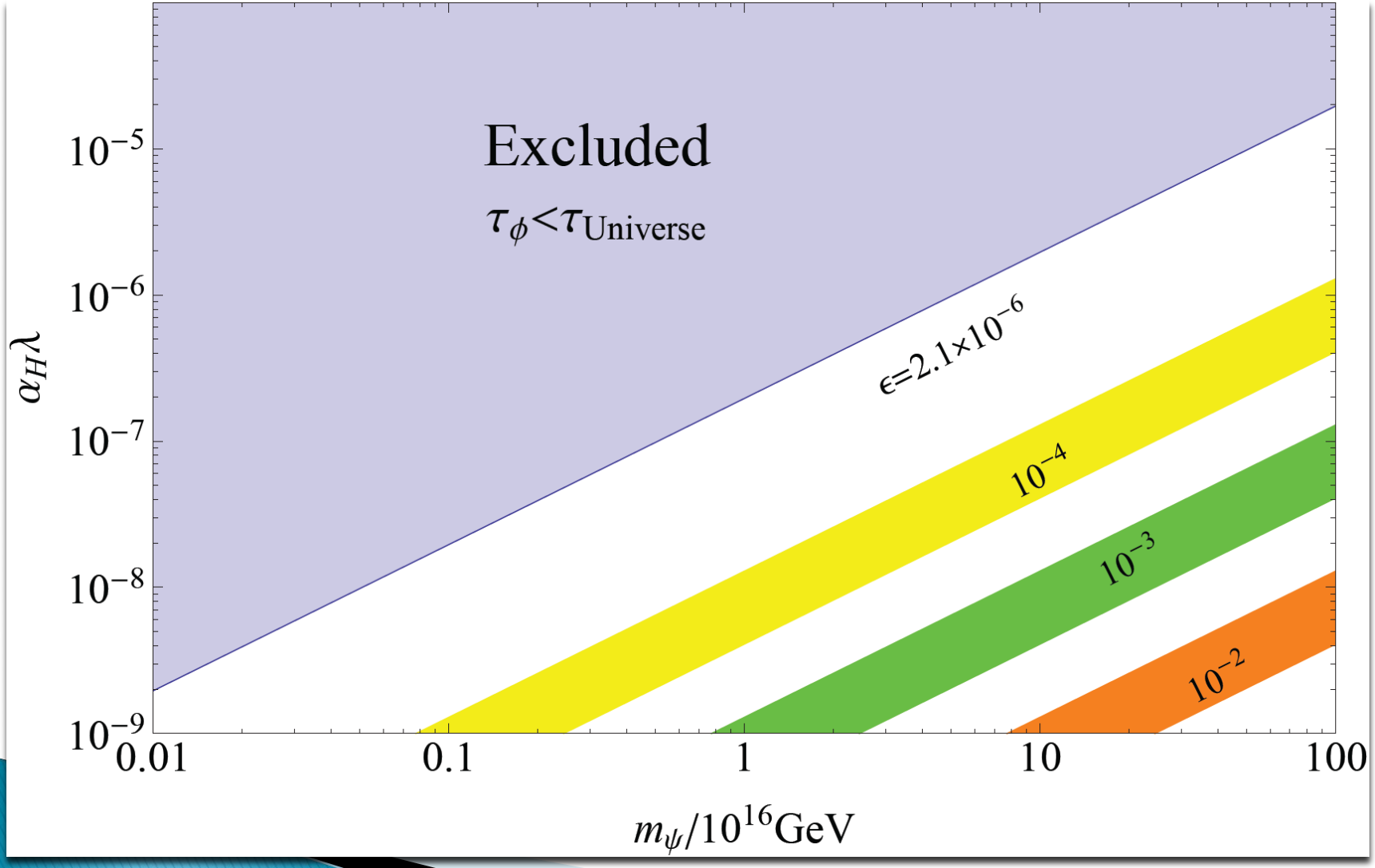
$$\Gamma(\phi \to \gamma_H \gamma)^{-1} \approx 1.52\mathcal{C} \times 10^{53}\,{\rm GeV}^{-1}$$

$$\Gamma(\phi \to \gamma_H \gamma_H) : \Gamma(\phi \to \gamma\gamma_H) : \Gamma(\phi \to \gamma\gamma) \simeq 1 : \epsilon^2 : \epsilon^4$$

$$\Rightarrow \quad \epsilon \approx \frac{4.1 \times 10^{-13}}{\alpha_H \lambda \sqrt{\mathcal{C}}} \left(\frac{m_\psi}{10^{16}\,{\rm GeV}}\right) \quad \text{for} \quad m_\phi = 260{\rm GeV}$$

Result of D5 Op. case

JCP & S.C.Park,
arXiv: 1207.4981



Conclusion

- 130 GeV peak (3~4 σ) from the Fermi-LAT data?
- $< \sigma v>_{\gamma\gamma} \sim 2 \cdot 10^{-27}$ cm^3/s with m_{DM}=130 GeV

  cf. $< \sigma v>_{thermal} \sim 3 \cdot 10^{-26}$ cm^3/s
- Decay models are acceptable for DM profiles enhanced around the GC.
- DM decay? -> $\Gamma^{-1}_{DM} \sim 10^{28\text{-}29}$ s with $m_{DM} \sim 260$ GeV

  Two sols. -> D6 Op. or D5 Op. W/ additional suppressions.

Thank you