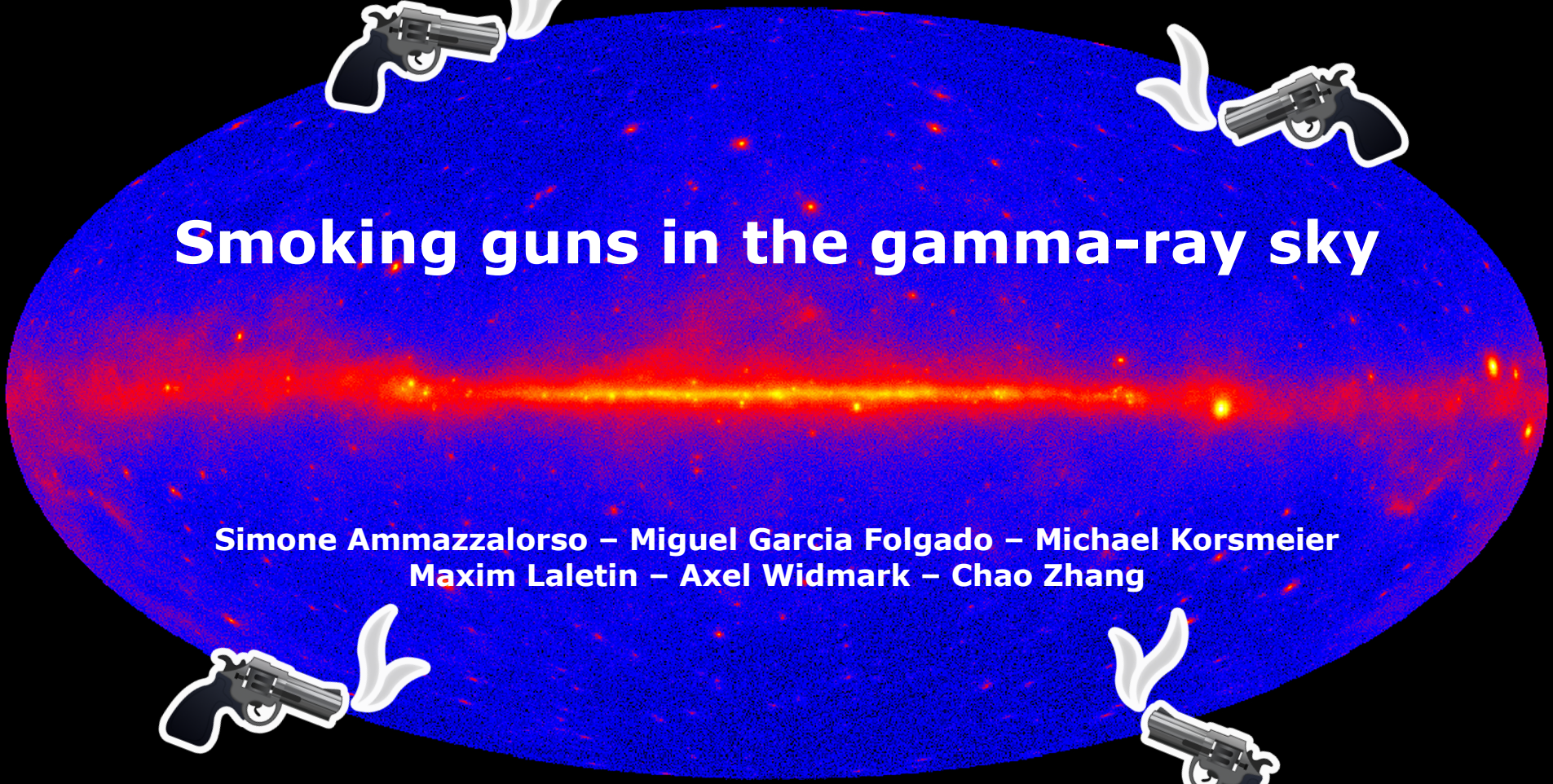
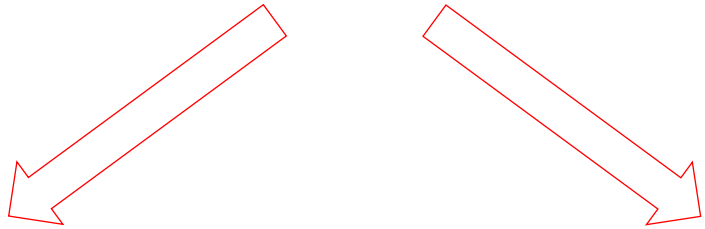


Smoking guns in the gamma-ray sky

Simone Ammazzalorso – Miguel Garcia Folgado – Michael Korsmeier
Maxim Laletin – Axel Widmark – Chao Zhang

What would make for a convincing signal of particle dark matter in the gamma ray sky?

Gamma rays from DM



Annihilation
$\sim\rho^2$

Decay
$\sim\rho$

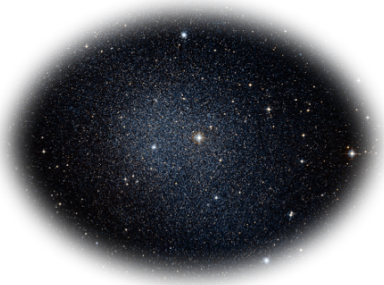
Different search strategies are needed

Where to look for DM annihilation?

J-factors

$$\Phi_\gamma = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{sM_\chi^2}\sum_i Br_i\frac{dN_\gamma^i}{dE}\times J \qquad \mathrm{J}(D,\Delta\Omega) = \int_{\Delta\Omega}\int_{\mathrm{l.o.s.}}\rho^2_{\mathrm{DM}}(r(s))\mathrm{d}s\mathrm{d}\Delta\Omega'$$

Galactic center
J = 10^{22} – 10^{23}



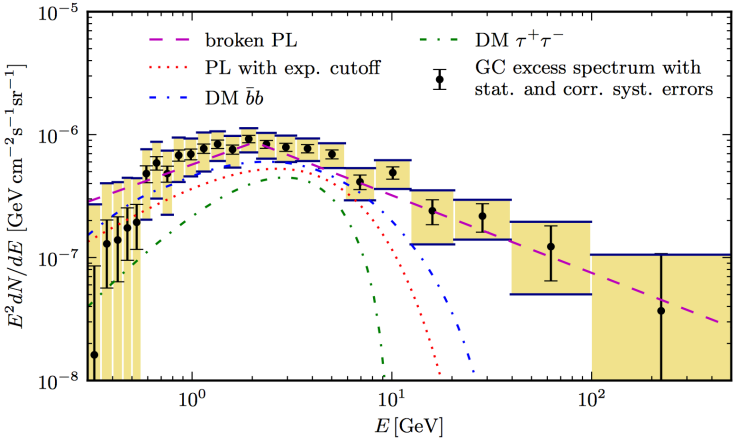
Dwarf spheroidals
J = 10^{17} – 10^{19}

Galaxy clusters
J = 10^{15} – 10^{19}

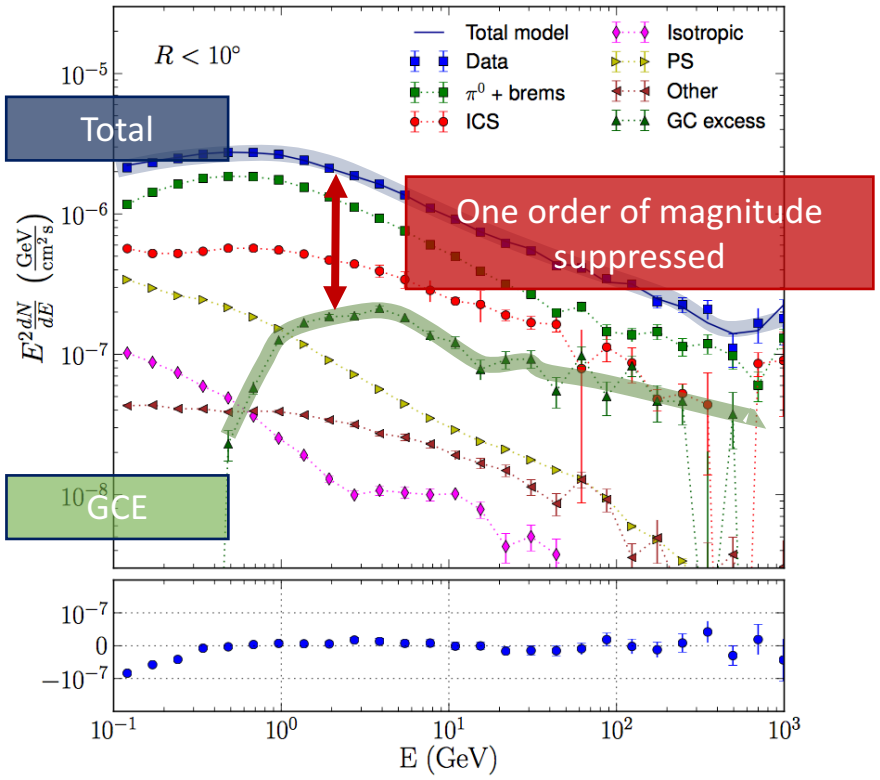
(in units GeV^2/cm^5)

Galactic center: How to search for DM?

At the example of the observed gamma-ray Galactic center excess at about 2 GeV.



Calore+ 2014 Background model systematics for the Fermi GeV excess



Fermi-LAT 2017 THE Fermi GALACTIC CENTER GEV EXCESS AND IMPLICATIONS FOR DARK MATTER

Determination through a template fit:

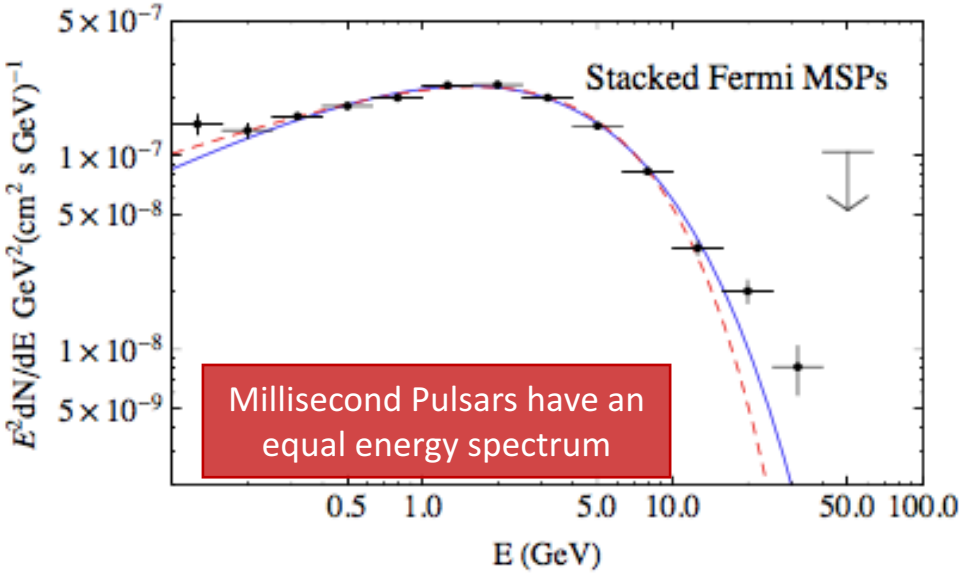
- Hadronic interactions and bremsstrahlung
- Inverse Compton scattering
- GC excess
- Isotropic emission
- Point sources
- Extended sources, Cygnus, LMC
- Loop I
- Sun and Moon templates
- (Fermi bubbles)

Galactic center: What's the difficulty?

Problem

- Many gamma-ray sources at the center
- Astrophysical background is not well known

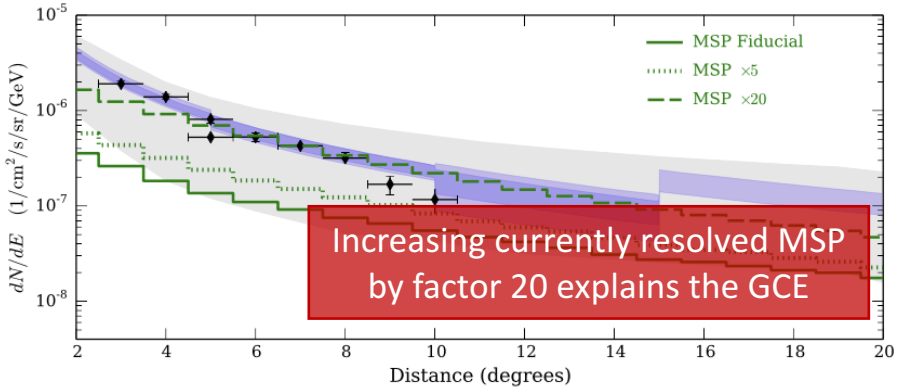
- Signal to background ratio is low => DM and astrophysics might easily be confused e.g.



FERMILAB-PUB-14-236-A: A NEWDETERMINATION OF THE SPECTRA AND LUMINOSITY FUNCTION OF GAMMA-RAY MILLISECOND PULSARS.

Approach

- Identification of point sources in the Galactic center, e.g. with X-rays



O'LEARY+ 2016 YOUNG AND MILLISECOND PULSAR DEV GAMMA-RAY FLUXES FROM THE GALACTIC CENTER AND BEYOND.

Dwarf spheroidals: The perfect place to search?

24 dSphs around the Milky Way
9 ”classical” (discovered in previous century)
15 ”ultra-faint” with very little baryonic matter
All of them are devoid of gas

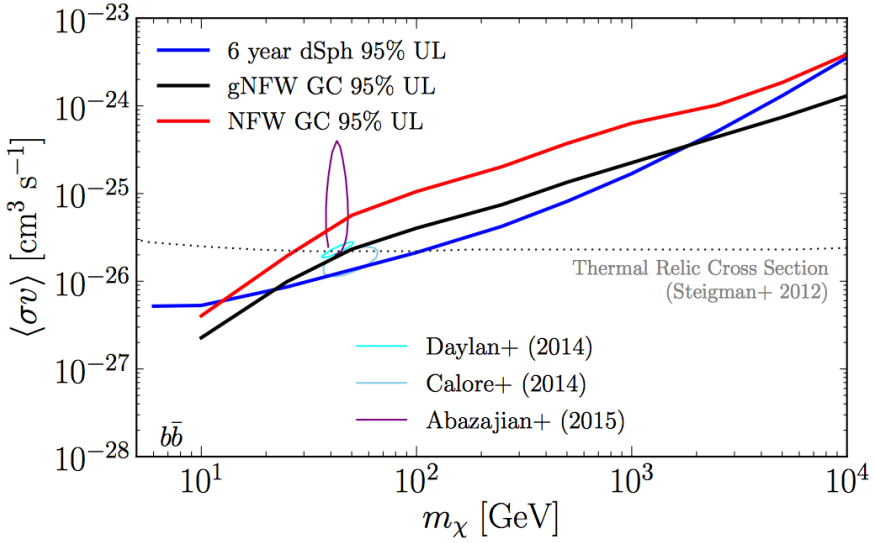
Why to look at dwarfs?

- Galactic center is a the most plentiful source, but suffers from a backgrounds
- Dwarf galaxies are cleaner
- Possible future observation signals are more convincing

Largest systematic uncertainty

- Dark matter density profile

Comparison of DM annihilation sensitivity between Galactic center and dwarfs

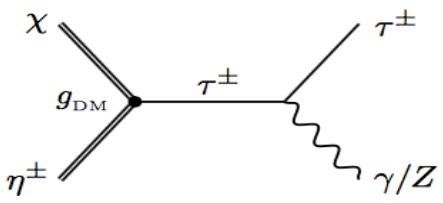


Fermi-LAT THE Fermi GALACTIC CENTER GEV EXCESS AND IMPLICATIONS FOR DARK MATTER

Theory: How to boost annihilation?

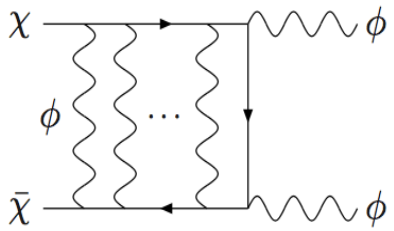
Coannihilation

- Thermal production in the early Universe can be affected by other (heavier) dark sector particles
- This changes the annihilation rate
- Boost by several orders of magnitude



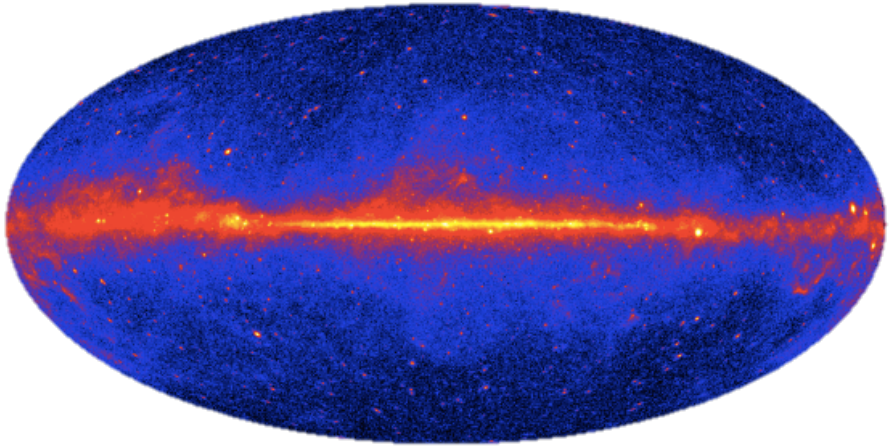
Sommerfeld

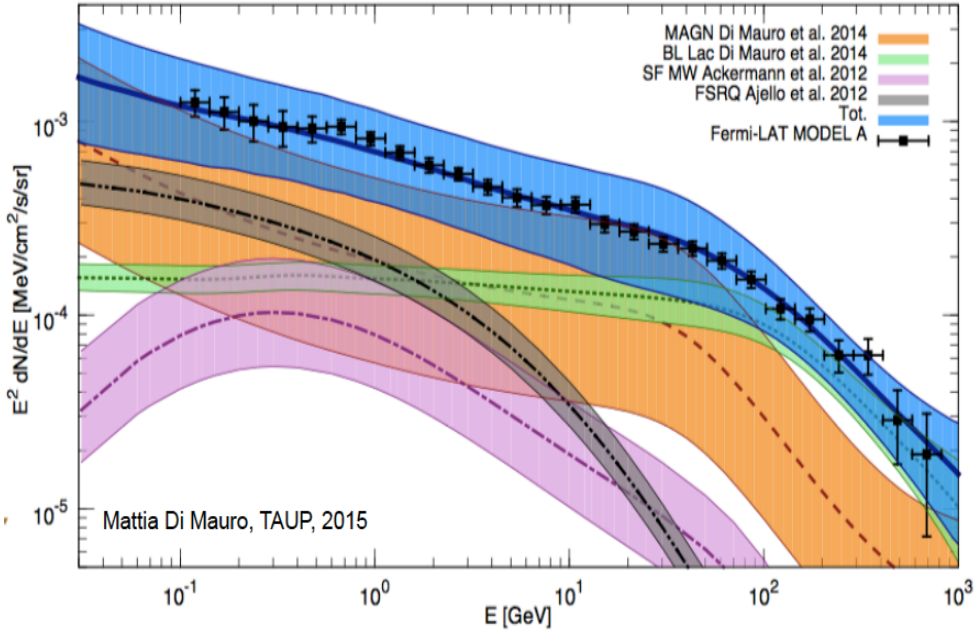
- Due to new (BSM) long range forces
- Speculated to boost annihilation by up to 9 orders of magnitude



Where to look for DM decays?

Decaying DM signal provides a more isotropic signal, which can be probed with isotropic gamma-ray background (IGRB)





To produce a noticeable contribution above 100 GeV one needs to have DM lifetime of order

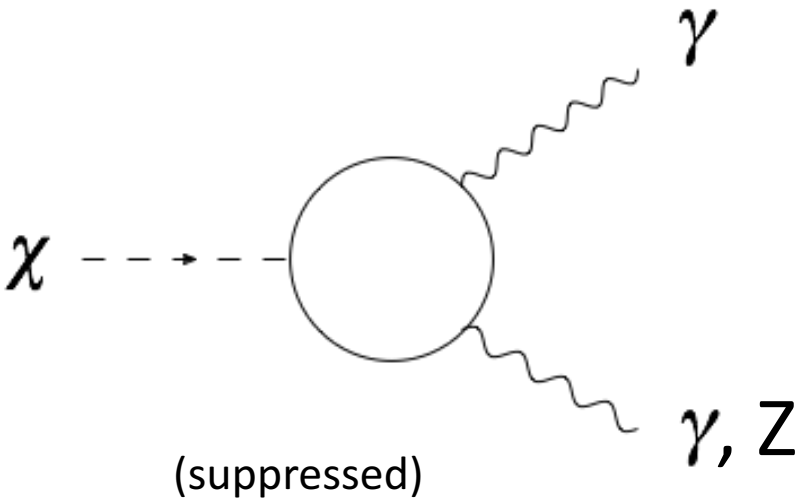
$$\tau \sim 10^{28} - 20^{31}\ s$$

Spectral features

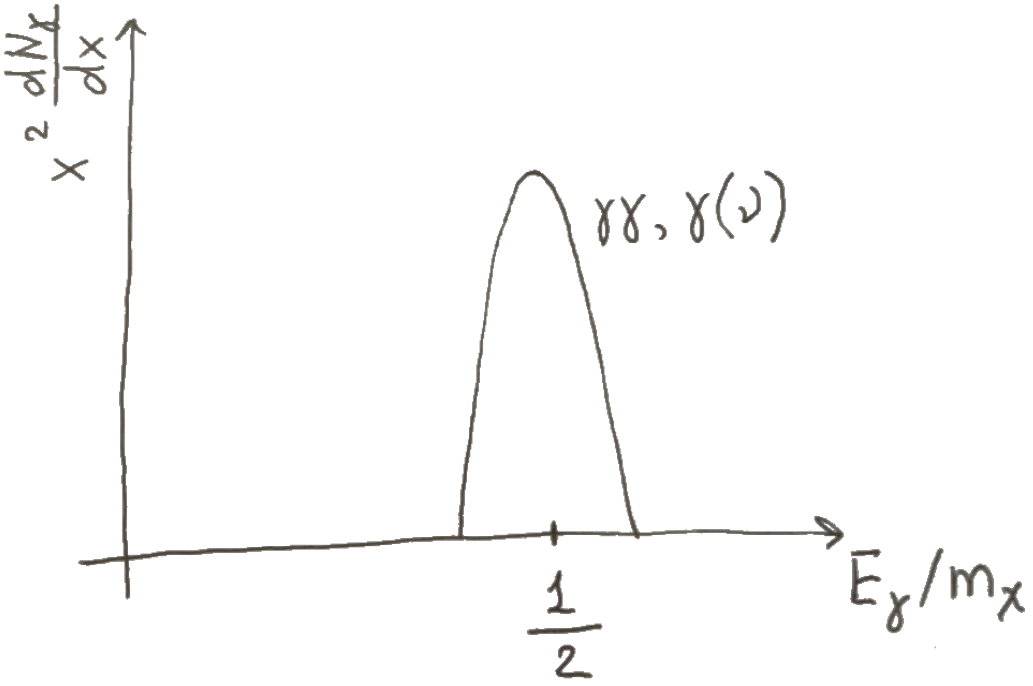
Spectral features can provide a clear smoking gun signature for both annihilating and decaying dark matter

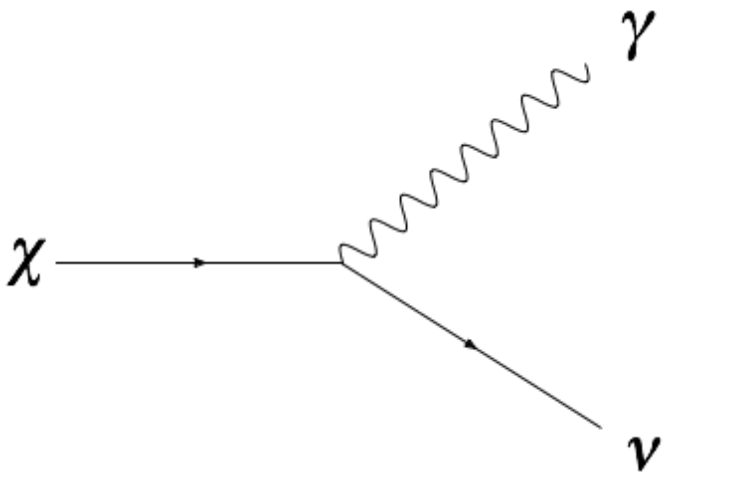
- Lines
- Boxes
- Triangles
- etc.

Lines



(suppressed)



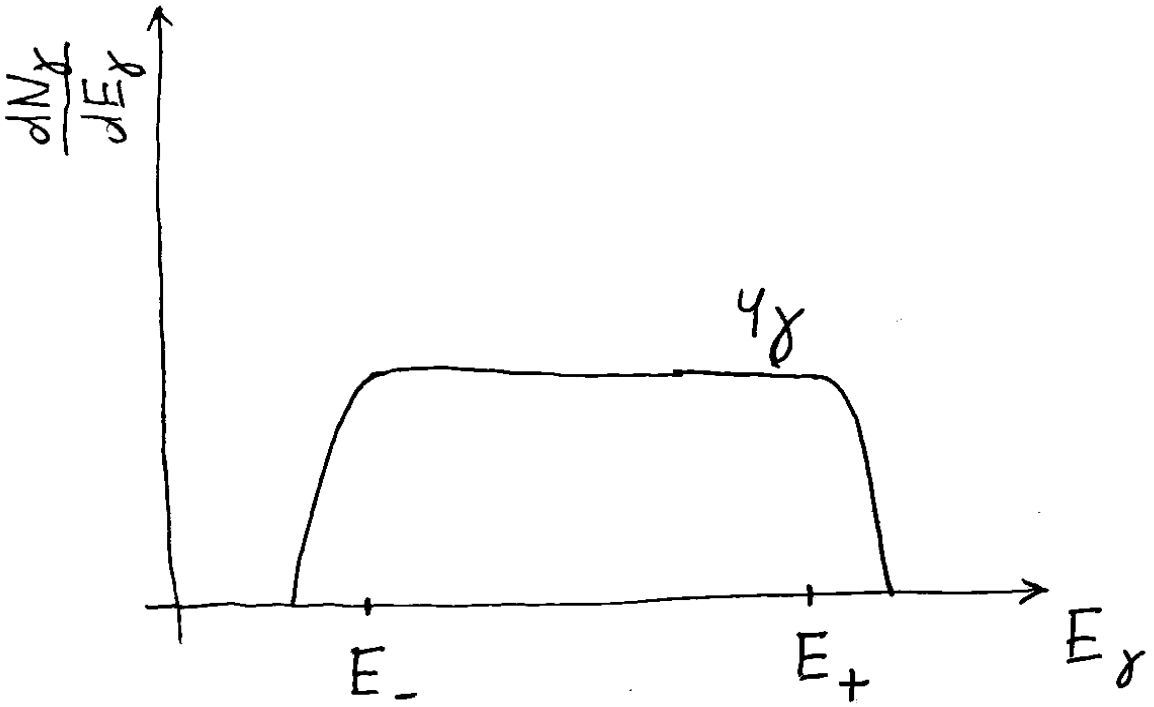


Ibarra+, Int.J.Mod.Phys., 2013

Boxes

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

$$m_\chi > m_\phi$$

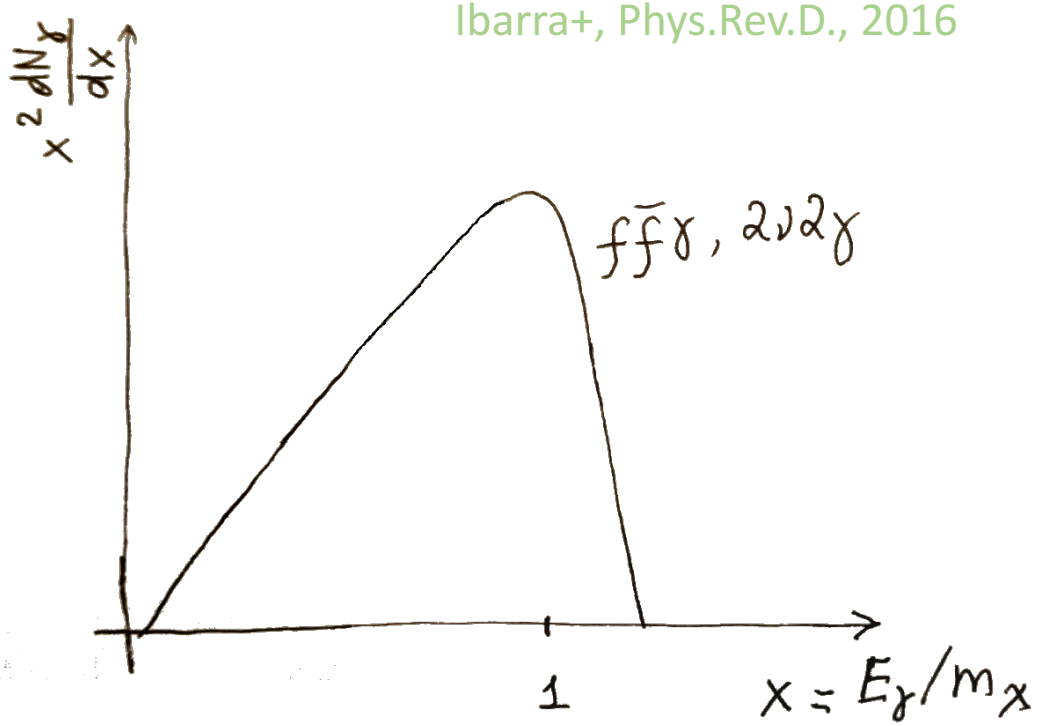


$$E_\pm = (m_\chi/2)\left(1 \pm \sqrt{1-(m_\phi/m_\chi)^2}\right)$$

Ibarra+, JCAP, 2012

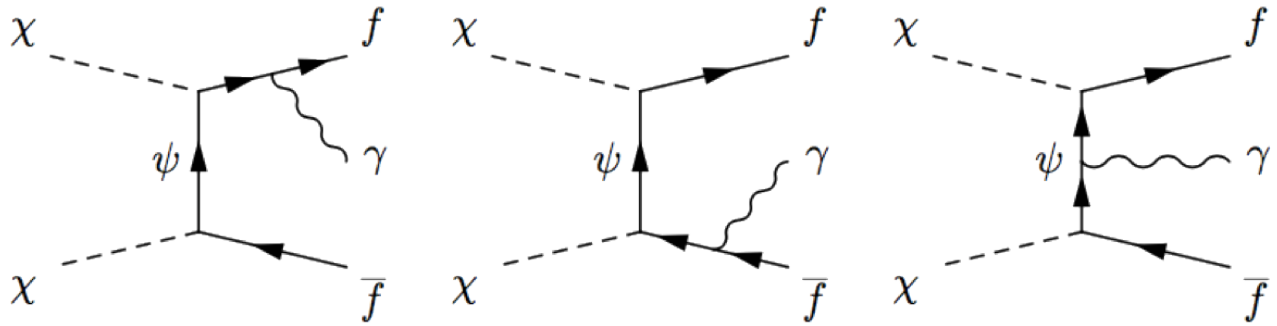
Triangles

Ibarra+, Phys.Rev.D., 2016

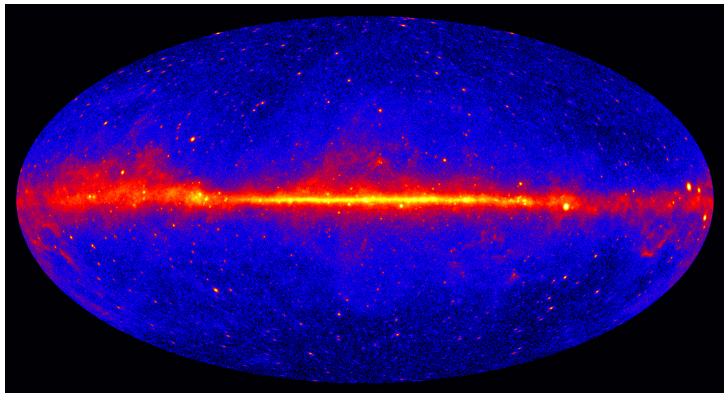


$$\chi\chi \to \phi\phi \to 2\gamma 2\nu$$

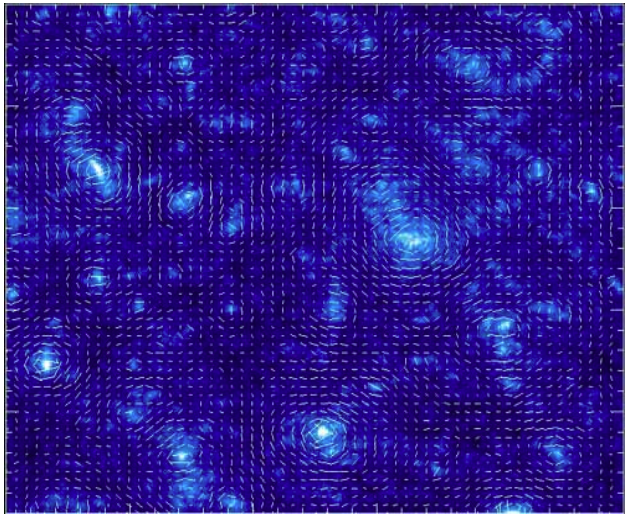
or internal bremsstrahlung



Cross correlations: A clever idea to look for DM signals from massive regions



X



- Visible matter (i.e. clusters) trace DM density
- Any DM signal is expected to be correlated with the mass distribution (cosmic shear, weak lensing, galaxy distribution,…)

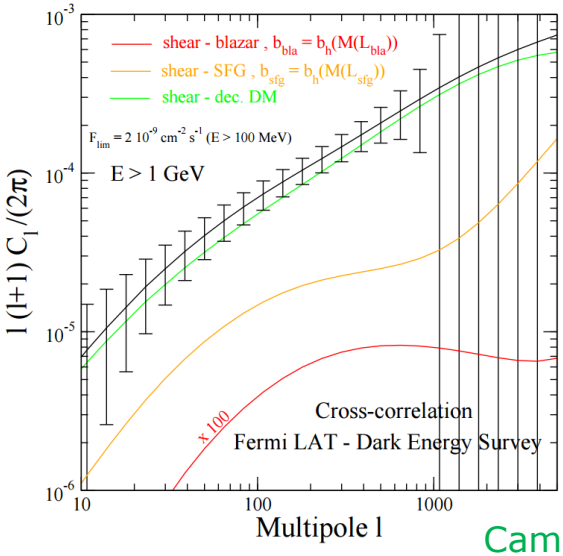
Task: Measure and calculate prediction for correlation multipole moments

$$\langle I(\vec{n}_1) I(\vec{n}_2) \rangle \longrightarrow C(\theta) \longrightarrow C_l$$

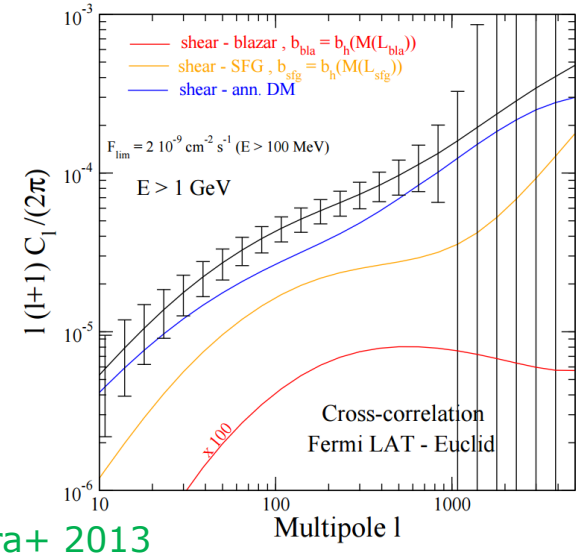
Cross correlations: Sensitivity prediction

- Excellent sensitivity for annihilation and decay
- Systematic uncertainty due to DM halo modelling

Decay



Annihilation



Camera+ 2013

For a 100 GeV DM mass and thermal cross-section the signal is larger that background; this is a smoking gun for detection.

Conclusion

- Annihilating and decaying dark matter scenarios require different strategies:
  - Dwarf spheroidals – perfect for *annihilating* DM
  - IGRB – for *decaying* DM
- Some models with extended dark sector can provide the boost of DM annihilations.
- Energy spectrum morphology are important for both annihilations and decays and would make a convincing discovery
- Cross-correlations – another way of looking for DM in gamma rays
- Improving angular and energy resolution is crucial for smoking gun signature detection.

Backup

Particle models with coannihilation

year	model	Boost factor in <σv>
1991,K.Greist	LSP+squarks, Nx=2, g2/g1=3 to 18, σv22=Aσv21=A2σv11	increase [200,350)
1992, Satoshi Mizuta	Higgsino-Dominant LSPs. H˜S,AH˜± →ffbar mediated by the W.	much larger than that of the annihilation
1997, Joakim Edsjo,Paolo Gondolo	Heavy higgsino-like neutralinos.	increase [2,10)
	Models with |μ| ~ |M1|. if lightest neutralino is more higgsino-like or gaugino-like.	increase [1,100)
2006,Kyoungchul Kong et al.	Kaluza-Klein Dark Matter with Universal Extra Dimensions.	reduce the effective annihilation cross-section, and therefore increase the LKP relic density.
…	… (lots of work)	...
2016, John Ellis et al.	Gluino-neutralino coannihilations.	s channel leading to a smaller gluino annihilation cross section and hence a larger relic density.
2017	EFT/Simplified models of dark matter.	Depending on the mass spectrum and interaction.(increase or decrease)

Particle models with lines

- Gravitinos in R-parity violating vacua (or sneutrino in bilinear R-parity breaking)
- Hidden SU(2) vectors

Ibarra+, Int.J.Mod.Phys., 2013

Cross correlations

Correlation signal Window functions Halo model

$$C_l^{(\gamma\,shear)} = \int \frac{d\chi}{\chi^2} W_\gamma(\chi)\, W_{shear}(\chi)\, P_{\gamma\,shear}\left(k=\frac{l}{\chi},\chi\right)$$

DM annihilation/decay

Background:
- Blazar
- SFG
- mAGN

Fornengo+ 2015