Dark Matter indirect searches and tests of Lorentz invariance violation with the Fermi Large Area Telescope

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on behalf of the Fermi LAT collaboration

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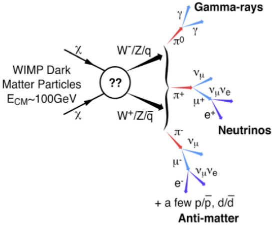
Outline

- ~~The Fermi observatory and the Large Area Telescope~~
  - Deferred to the "Cosmology and Astrophysics" session, tomorrow afternoon at 2:00 pm
- Indirect Dark Matter Searches in γ-rays with Fermi
  - Basic search strategies
  - A few selected topics and related limits
  - Direct cosmic-ray measurements also deferred to tomorrow
- ~~Direct cosmic-ray measurement and indirect DM searched~~
  - Also deferred to tomorrow
- Gamma-Ray Bursts and tests of Lorentz invariance
  - Mainly the short GRB 090510
- Conclusions

Gamma-ray production from Dark Matter

"Particle physics factor"
(from theory)

$$\frac{d\Phi}{dE_\gamma}(E_\gamma, \phi, \theta)\ ^{1} \quad = \quad \boxed{\frac{1}{4\pi}\frac{\langle \sigma_{\mathrm{ann}} v\rangle}{2m^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma} B_f} \quad \times \quad \boxed{\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\text{line of sight}} \rho^2\left(l(\phi')\right) dl(\phi')}$$



Dark Matter distribution
(from measurements and simulations)

- Expected flux
  - (Particle Physics) Model dependent
  - DM distribution subject to large uncertainties
  - Astrophysical "backgrounds"
- Measured flux (from the detector)
  - Instrument related systematics

[1] For Dark Matter decay (rather than annihilation): $\langle \sigma_{\mathrm{ann}} v\rangle / 2m^2 \to 1/\tau m$, $\rho^2 \to \rho$

Fermi: Dark Matter search strategies

Galactic center

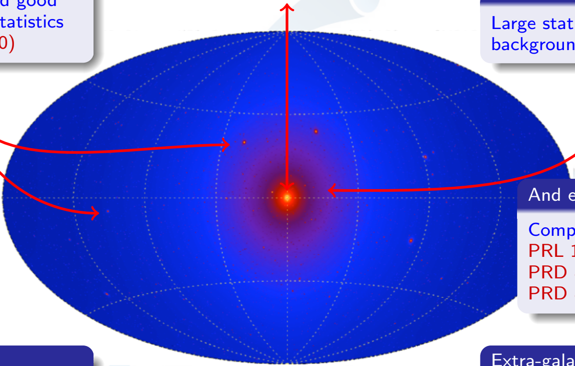
Good statistics but source confusion and diffuse background

Satellites

Low background and good source id, but low statistics
ApJ, 712, 147 (2010)

Milky Way halo

Large statistics but diffuse background



And electrons/positrons!

Complementary to γs
PRL 102, 181101 (2009)
PRD 82, 092004 (2010)
PRD 82, 092003 (2010)

Spectral lines

No astrophysical uncertainties, good source id but small branching ratio
PRL 104, 091302 (2010)

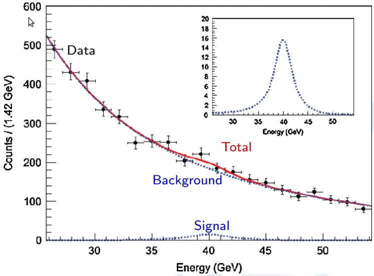
Galaxy clusters

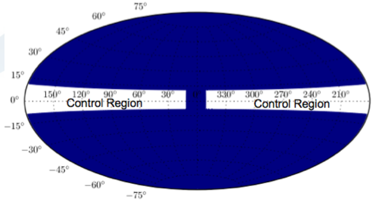
Low background but low statistics
JCAP 05, 025 (2010)

Extra-galactic γ radiation

Large statistics, but astrophysics and galactic diffuse background
JCAP 04, 014 (2010)

All-sky map of gamma-rays from DM annihilation from arXiv:0908.0195 (based on Via Lactea II simulation)

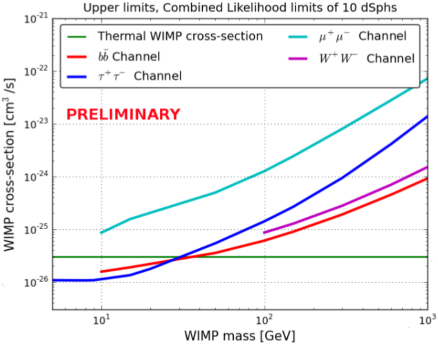




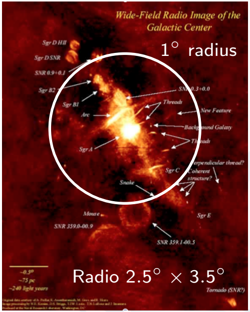
- Dark matter particle annihilation or decay into $\gamma + X$ can produce monochromatic gamma-rays
  - Optimal energy resolution ($\approx 10\%$ at 100 GeV) and calibration very important for this analysis
- No detection in the first 23 month of data between 7 and 200 GeV
  - High latitude ($|b| > 10^\circ$) plus 20° degrees around the Galactic center
- Model-dependent upper limits on DM cross section or lifetime
  - Limits on $\langle \sigma v \rangle$ too weak to constrain typical thermal WIMP models

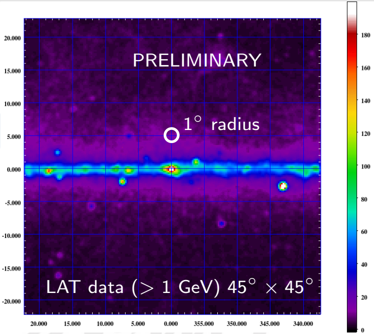
Dwarf spheroidal galaxies

- System with very large mass/luminosity ratio
  - 25 discovered so far, more will be by current/upcoming experiments
- Select most promising candidates for observations
  - Selection based on proximity (within 180 kpc from the Sun), latitude (more than 30° from the Galactic plane), stellar kinematic data
  - Most of them are expected to appear as point sources
- Complementary systematic blind search for DM satellites
- No detection by Fermi with 11 months of data, Abdo et al., ApJ **712**, 147 (2010)
- Update based on 24 months of data will be published soon
  - Combined likelihood of 10 dSph
- Start to cut into parameter space below the thermal WIMP cross-section for low masses



Galactic center

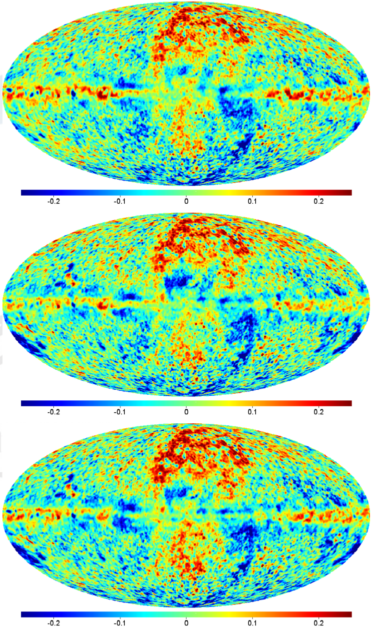




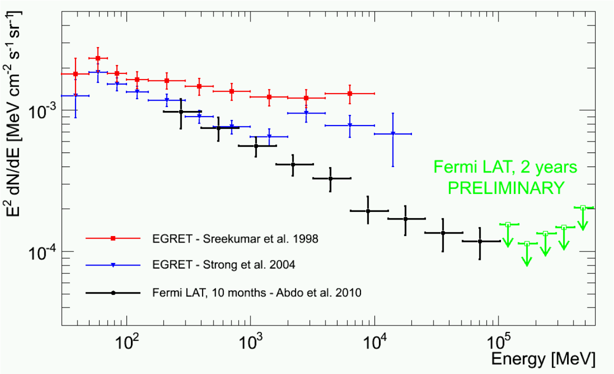
- Steep DM profiles, expect large DM annihilation signal
- Very complicated region, understanding of the astrophysical background is crucial to extract a potential DM signal
  - Source confusion, modeling of the Galactic diffuse emission
- Major ongoing analysis effort (DM, diffuse emission, catalog)
  - Diffuse emission removed using a *physically-motivated* model
  - Peaks in residual emission consistent with known sources
  - Work in progress to characterise the low-level residual structures and point sources

Galactic halo

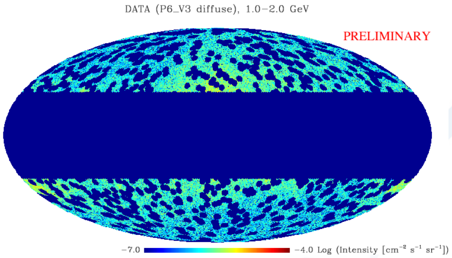
- Exploits both spectral and spatial information
    - Data binned in E and angle
- Large residuals in the fit *might* indicate a DM component
    - Scan model parameters of diffuse emission that affect more significantly DM limits
    - Compute limits assuming all diffuse emission is DM (conservative)
- Analysis challenge: residual maps from a selection of GALPROP models show considerable large scale structures
    - In many cases just a limit of the diffuse model

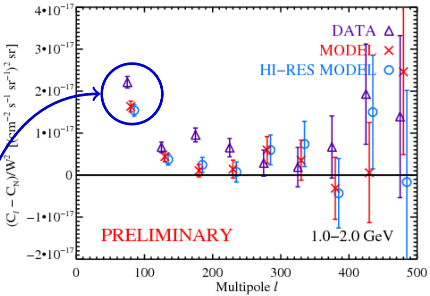


Isotropic γ-ray background



- All sky spectrum
  - Clean sample to extend beyond 100 GeV and prob higher energy WIMPs
  - Major contribution from galactic diffuse emission
- Caveats for constraining DM
  - Modeling astrophysical contribution
  - Effects from cosmological DM distribution and photon propagation effects (EBL)

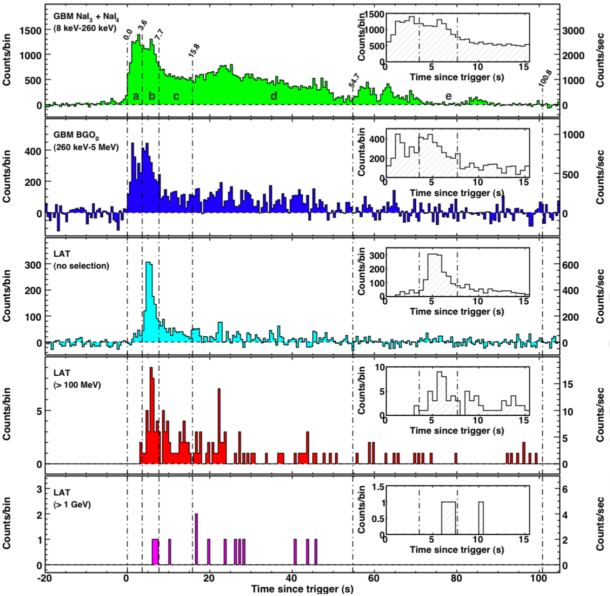




Contamination by Galactic diffuse emission

- Search for anisotropies of diffuse gammas through angular power spectrum
- Benefits from LAT full sky coverage, uniform exposure, angular resolution
- Potential to reveal un-modeled source classes, including DM
  - In the form of excess fluctuations on small angular scales (larger wrt truly diffuse emission)

- GRBs are the most energetic explosions in our Universe
  - Huge energy released in keV-MeV gamma rays
  - $E_{iso} > 10^{54}$ erg for the brightest bursts
  - $E \approx 10^{51}$ erg for a beaming factor of 10^{-3}
- Well studied at *low* (optical to MeV gamma rays) energy in the past two decades:
  - Bimodal duration distribution: *short* (≈ 1 s) burst and long ($\approx$ tens of seconds) bursts (different progenitors?)
  - Cosmological origin (it has been announced last week that the photometric redshift of GRB 090429B is estimated to be 9.2!)
  - Rapid (ms) variability in the light curves
- Not very much information above 100 MeV before Fermi
- From our prospective (more on this later) they are interesting because:
  - Emission extends to very high energy
  - Photon propagation over cosmological distances
  - They're short!



GRB 080916C

- 145 photons above 100 MeV
- 3 photons above 10 GeV
- Highest energy photon: 13.2 ± 0.7 GeV
- Can study for the first time fine time structures at high energy
- Good localization, follow up by other instruments photometric redshift of $z = 4.35 \pm 0.30$
- Evidence for a delay of the high-energy emission (spectral evolution), seems a feature common to many Fermi GRBs

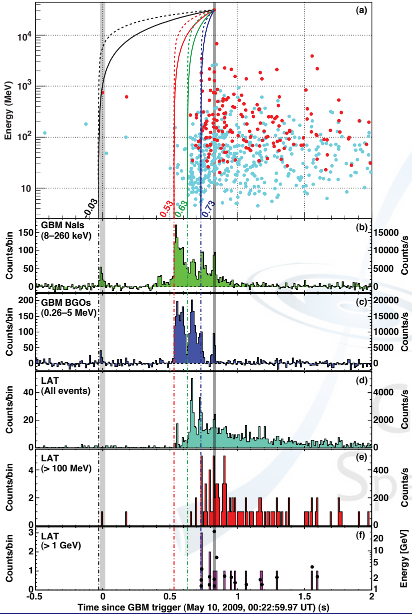
- Several theoretical frameworks that predict (or can accommodate) LIV at sufficiently high-energy
  - Expand the photon dispersion relation in powers of $E/M_{\rm QG}$
- Time-delay experiments testing *subluminal* or *superluminal* propagation in vacuum
  - The linear term for small distance is

$$\lim_{z\to 0} \Delta t = \pm \frac{\Delta E}{M_{QG,1}} L = \pm \frac{\Delta E}{M_{QG,1}} H_0 z$$

  - For cosmological distances

$$\Delta t = \pm \frac{\Delta E}{M_{QG,1}} \int_0^z \frac{1+z}{H_0\sqrt{\Omega_\Lambda + (1+z^3)\Omega_m}} dz$$

- Need large ΔE and large z (and need to measure z)!
  - Make GRBs for the perfect candidates



GRB 090510

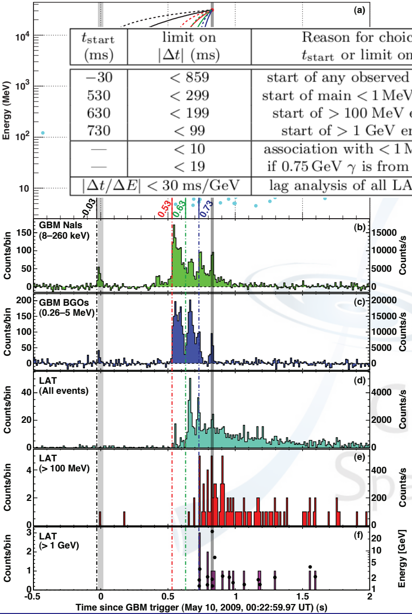
- A 31 GeV photon detected 0.829 s after the GBM trigger ($z = 0.903 \pm 0.003$)
- We don't know when the photon has been emitted!
- Very reasonable assumption: the photon has not been emitted before the beginning of the burst. This translates into an upper limit on a possible (positive) time delay

$$\Delta t > 860 \text{ ms}$$

and a lower limit for the LIV (in a subluminal scenario) mass scale

$$M_{QG,1} > 1.19 M_p$$

(the most stringent so far)



GRB 090510

$t_{\rm start}$ (ms)	limit on $\|\Delta t\|$ (ms)	Reason for choice of $t_{\rm start}$ or limit on Δt	E_l (MeV)	valid for s_n	lower limit on $M_{\rm QG,1}/M_{\rm Planck}$	limit on $M_{\rm QG,2}$ in 10^{10} GeV/c^2
−30	< 859	start of any observed emission	0.1	1	> **1.19**	> 2.99
530	< 299	start of main < 1 MeV emission	0.1	1	> **3.42**	> 5.06
630	< 199	start of > 100 MeV emission	100	1	> **5.12**	> 6.20
730	< 99	start of > 1 GeV emission	1000	1	> **10.0**	> 8.79
—	< 10	association with < 1 MeV spike	0.1	±1	> **102**	> 27.7
—	< 19	if 0.75 GeV γ is from 1st spike	0.1	−1	> **1.33**	> 0.54
$\|\Delta t/\Delta E\| < 30$ ms/GeV		lag analysis of all LAT events	—	±1	> **1.22**	—

(positive) time delay

$$\Delta t > 860 \text{ ms}$$

and a lower limit for the LIV (in a subluminal scenario) mass scale

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- Global lag analysis 2008972) can be used to constrain both subluminal and superluminal propagation.
- Stronger assumptions translate into more stringent limits.

Conclusions

- Indirect Dark Matter searches in Gamma-rays with Fermi
  - Point sources cleanest target: limits from dwarfs scratching WIMP benchmark thermal cross section around 10 GeV
  - All sky (EGB, line, anisotropies) accessible to Fermi only
  - Extended regions (halo, Inner Galaxy) promising but hard
  - Diffuse emission is the maximal uncertainty, need input from Fermi and other missions to improve modeling
- Gamma-ray bursts
  - Fermi opened a new era for the study of the high-energy emission
  - GRBs are straordinary laboratories for the study of fundamental physics
- Fermi is a 5 to 10 years mission
  - Theres much more to come!
  - More improvements are anticipated with better understanding of the detector response and more sophisticated analysis methods