Indirect detection, SUSY scans and application to *Fermi* data

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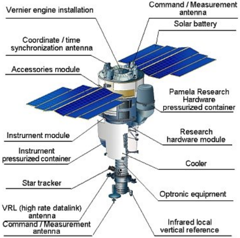
Slides available from `www.fysik.su.se/~pat`

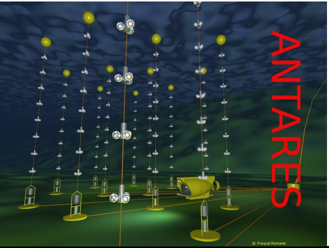
Indirect Detection

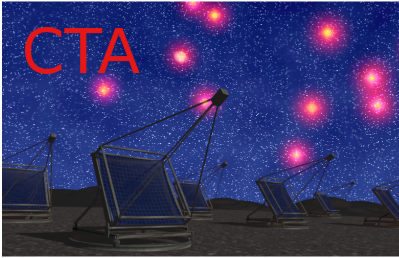
Indirect detection – WIMP annihilation producing

- positrons – PAMELA, *Fermi*, ATIC, AMS
- gamma-rays – *Fermi*, HESS, CTA
- anti-protons – PAMELA, AMS
- anti-deuterons – AMS, GAPS
- neutrinos – IceCube, ANTARES



PAMELA





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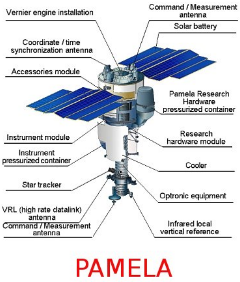

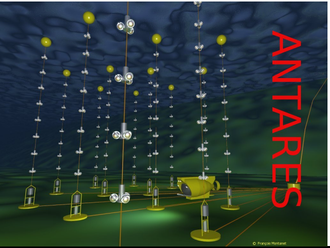

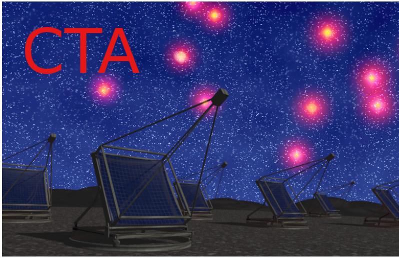

Likely targets

$\Phi \propto$ annihilation rate $\propto \rho^2_{\rm DM}$

- Galactic centre
- Galactic halo
- clusters & extragalactic diffuse (coming soon)
- dark clumps
- dwarf galaxies

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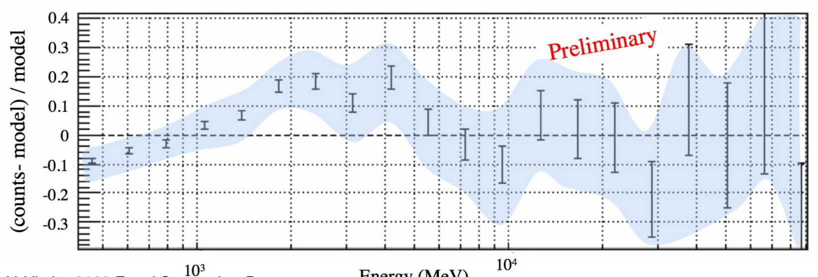
$7 \times 7^{\circ}$ around the GC



V. Vitale, *2009 Fermi Symposium* Poster

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  - Very high mass-to-light ratios
    $\Longrightarrow$ lots of DM, little BG
  - High latitude $\Longrightarrow$ low BG
  - $\Longrightarrow$ arguably the best targets for WIMP gammas

Two different approaches to including ID (or even DD) data in SUSY scans

1. Just use the published limits on $\langle \sigma v \rangle$ (or $\sigma_{\mathrm{SI,SD}}$)
   - Fast – can cover large parameter spaces (cf. Are's talk)
   - Not so accurate – experimental limits are invariably based on theoretical assumptions, e.g. $b\bar{b}$ spectrum
   - Full likelihood function almost never available
2. Use the data points directly in SUSY scans
   - Slow – requires full treatment of instrument profile for each point
   - Accurate – can test each point self-consistently
   - Allows marginalisation over theoretical assumptions
   - Allows construction of full multi-dimensional likelihood function

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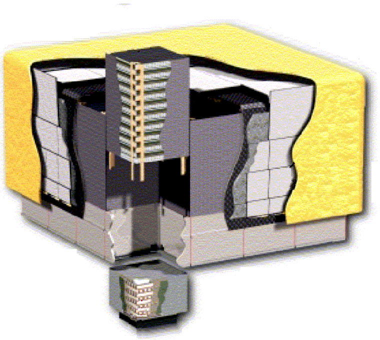
The *Fermi* Large Area Telescope (LAT)

- Overall modular design.
- 4×4 array of identical towers (each one including a tracker and a calorimeter module).
- Tracker surrounded by Anti-Coincidence Detector (ACD)



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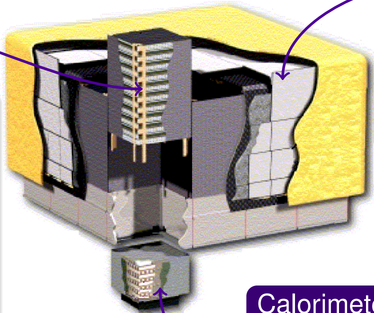

Tracker

- Silicon strip detectors, W conversion foils; 1.5 radiation lengths on-axis.
- 10k sensors, 80 m^2 of silicon active area, 1M readout channels.
- High-precision tracking, short dead time.

Anti-Coincidence Detector

- Segmented (89 tiles) to minimise self-veto at high energy.
- 0.9997 average detection efficiency.

Calorimeter

- 1536 CsI(Tl) crystal; 8.6 radiation lengths on-axis.
- Hodoscopic, 3D shower profile reconstruction for leakage correction.

Fermi-LAT Instrument Response Functions (IRFs)

- Effective area
- Point-Spread Function (PSF)
- Energy dispersion

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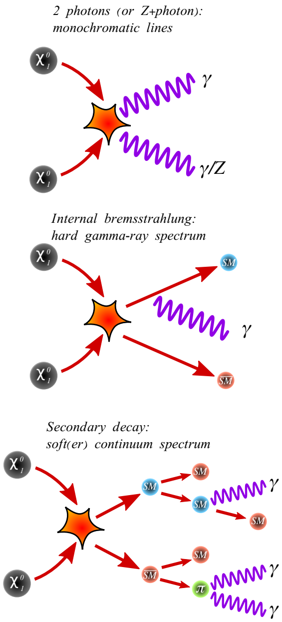
- FLATLIB - fast convolution library for processor-intensive model scans
- Source freely downloadable from www.fysik.su.se/~pat/flatlib

Gamma-rays from neutralino dark matter

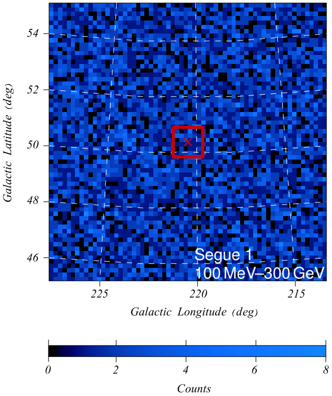


- 3 main gamma-ray channels:
  - monochromatic lines
  - internal bremsstrahlung
  - continuum from secondary decay

Segue 1 dwarf galaxy

Why Segue 1?

- Close(ish) – 23 kpc
- $M/L \sim 1300$ (**large**)
- The best S/N dwarf for WIMP gammas
- Leading the pack in *Fermi* dwarf upper limit analysis



Purposes:

- see if Segue observations do/will impact real models at all, considering 'soft bounds'
- attempt to validate dwarf UL analysis via an independent, rather different analysis

Scan setup

Data: Composite likelihood ($\mathcal{L}_1 \times \mathcal{L}_2 \equiv \chi^2_1 + \chi^2_2$) with

- dark matter relic density from WMAP
- precision electroweak tests at LEP
- LEP limits on sparticle masses
- B-factory data (rare decays, $b \to s\gamma$)
- muon anomalous magnetic moment
- and of course, *Fermi* observations of Segue 1

Model: Constrained MSSM (CMSSM)

- GUT boundary conditions on soft SUSY breaking parameters such that only 4 free parameters and 1 sign remain
- incorporates the simplest implementation of mSUGRA

Code: SuperBayes + DarkSUSY 5 + FLATlib

Including Segue 1 in SUSY scans

Same cuts as dwarf UL analysis

- “DIFFUSE” event class
- 105° zenith angle cut
- 10° ROI
- 14 energy bins from 100 MeV–300 GeV

Binned Poissonian likelihood (similar to dwarf UL analysis)

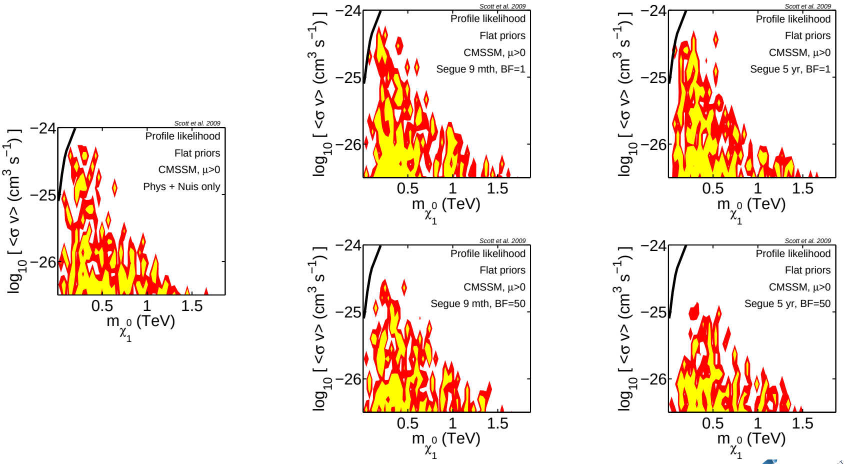
Spatial-spectral fit to inner 6×6 bins of 64×64 ROI (dwarf UL analysis assumes point source)

Segue 1 halo profile from best fit Einasto profile by Martinez et al. (2009; *JCAP* **6**:14) (NFW in dwarf UL analysis)

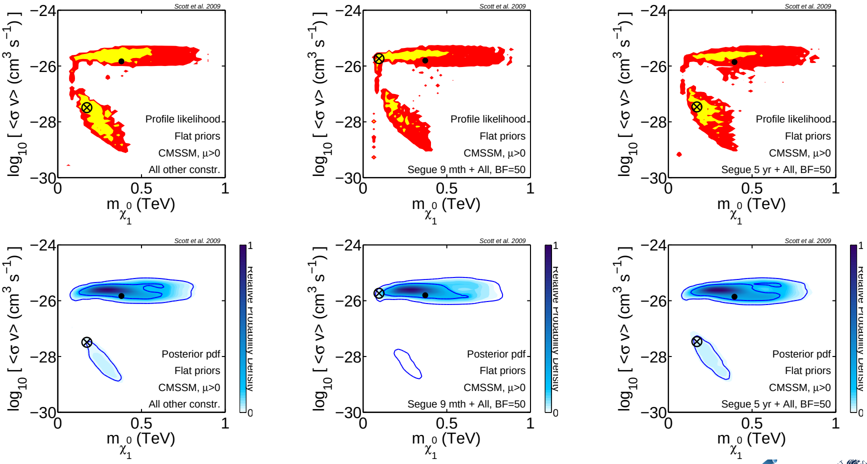
Including Segue 1 in SUSY scans

- Galactic diffuse BG from preliminary *Fermi* all-sky GALPROP fits
- Isotropic powerlaw extragalactic BG (as seen by *EGRET*)
- BG normalisations from dwarf UL fits (i.e. full $10^\circ \times 10^\circ$)
- Fast integration over energy-dependent IRFs (P6v3) with FLATLIB – (dwarf UL analysis skips energy dispersion)
- Inclusion of systematic errors from effective area and theoretical calculations – (dwarf UL analysis skips systematics)
- Integration into SUPERBAYES, upgraded with DARKSUSY 5 (including internal bremsstrahlung), bug fixes, etc.

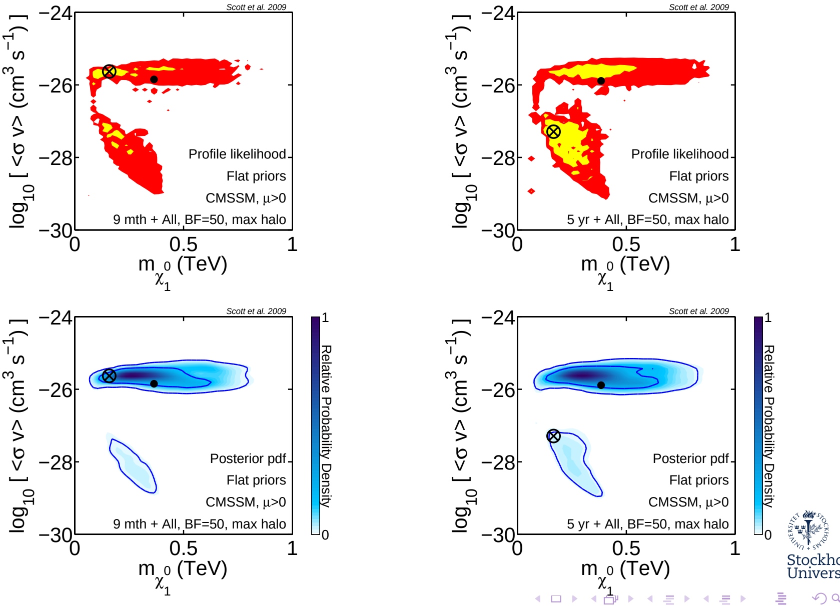
Results - Segue 1 only



Results - all observables + Segue 1



Using extreme (∼95% C.L. excluded) DM profile



Conclusions

- Existing 9 month dataset does constrain the CMSSM by itself, but only weakly
- 5 years of data will provide significantly better constraints, but...
- Not quite good enough to impact models which are not already disfavoured by other constraints (eg relic density)
- In the (unlikely) event of a later *signal* from Segue 1, we can zero in on the preferred CMSSM model and cross-section very quickly, and provide confidence intervals
- Consistent with limits found in the dwarf upper limit analysis
- FLATLIB source freely available from `www.fysik.su.se/~pat/flatlib`