Dark Matter Identification with Gamma Rays from Dwarf Galaxies

IDM 2010
8th International Workshop on Identification of Dark Matter

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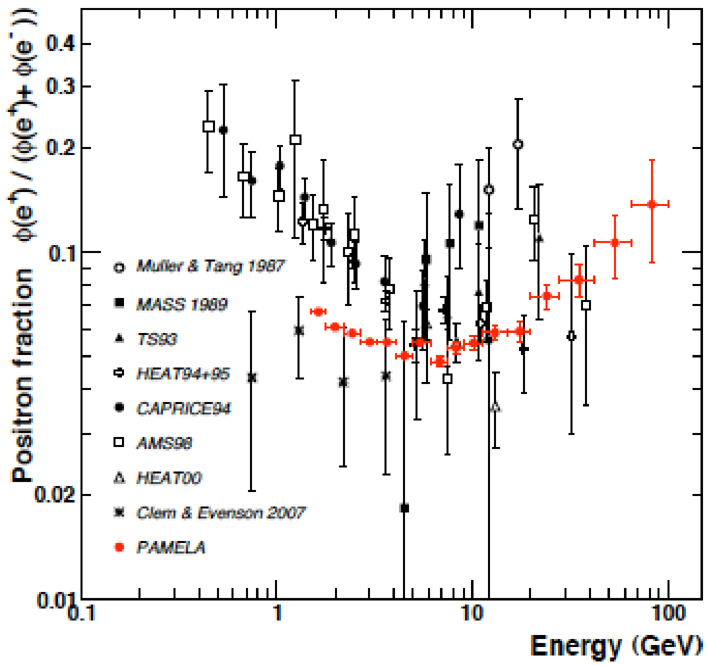
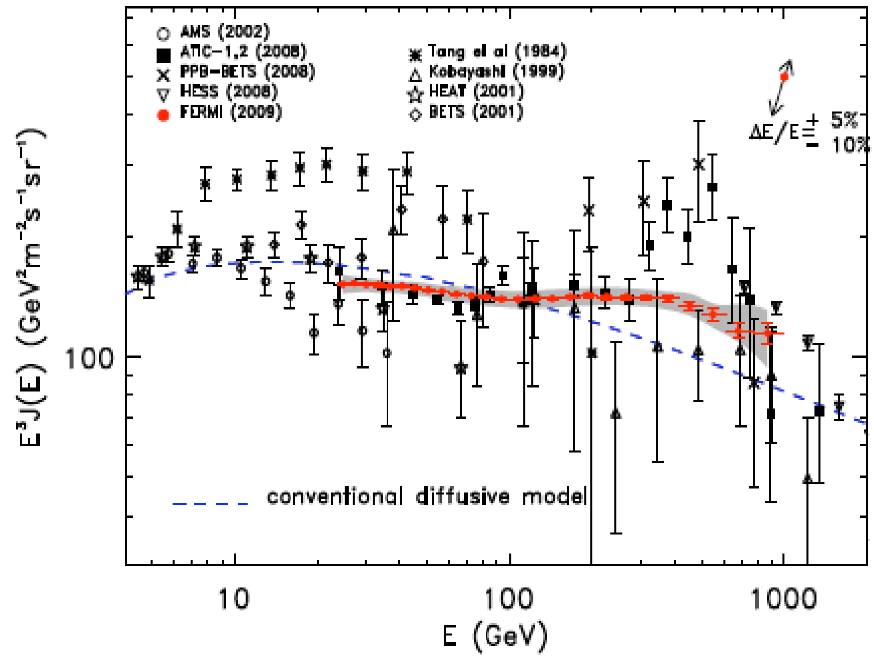
Based on arXiv:1007.0018 with Maxim Perelstein

Indirect Evidence of Dark Matter?



O. Adriani et.al.[PAMELA Collaboration], Nature 458, 607 (2009)



A.A.Abdo et.al.[The Fermi LAT Collaboration], Phys.Rev.Lett.102,181101 (2009)

Measurements of positron fraction in the 1-100 GeV range by PAMELA (left) and e^+e^- flux from 20 GeV - 1 TeV by Fermi (right) show excesses inconsistent with conventional astrophysical background expectations, fit well to leptophilic dark matter annihilation with boosted cross sections in the galaxy.

Will have accompanying signals in the form of energetic gamma rays.

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- What kind of gamma rays?

  Final State Radiation

  (dominates at high energies, model-independent and independent of astrophysical uncertainties)

- Look at:

  Dwarf galaxies

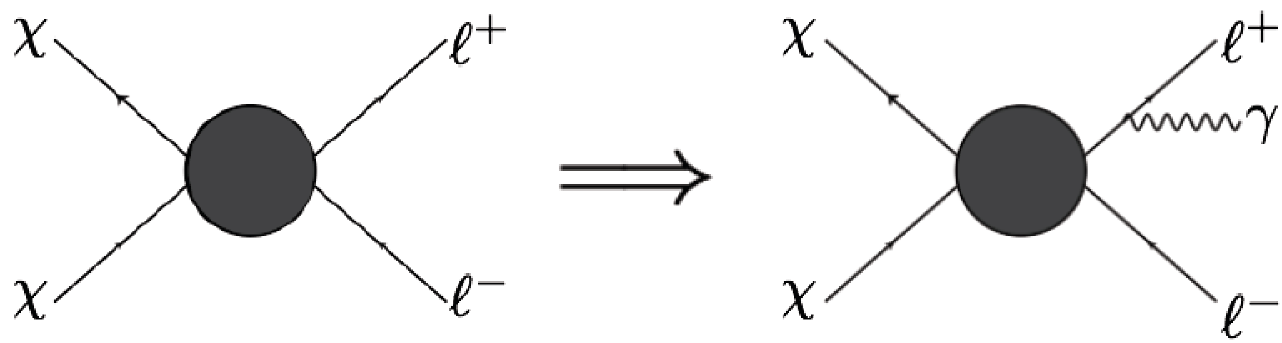
  (negligible background, clear direction)

- Use:

  Atmospheric Cherenkov Telescopes

  (large effective areas of observation)

Gamma Rays from Final State Radiation (FSR)



(Birkedal, Matchev, Perelstein, Spray, 2005)

• guaranteed in leptophilic (or any charged) annihilation channels

• dominant close to dark matter mass, has a sharp "edge" feature at this cutoff for 2-body final states

• spectrum independent of astrophysical uncertainties

• independent of details of the particle physics model; model-independent predictions can be made

(need to add on additional FSR from subsequent decay of products)

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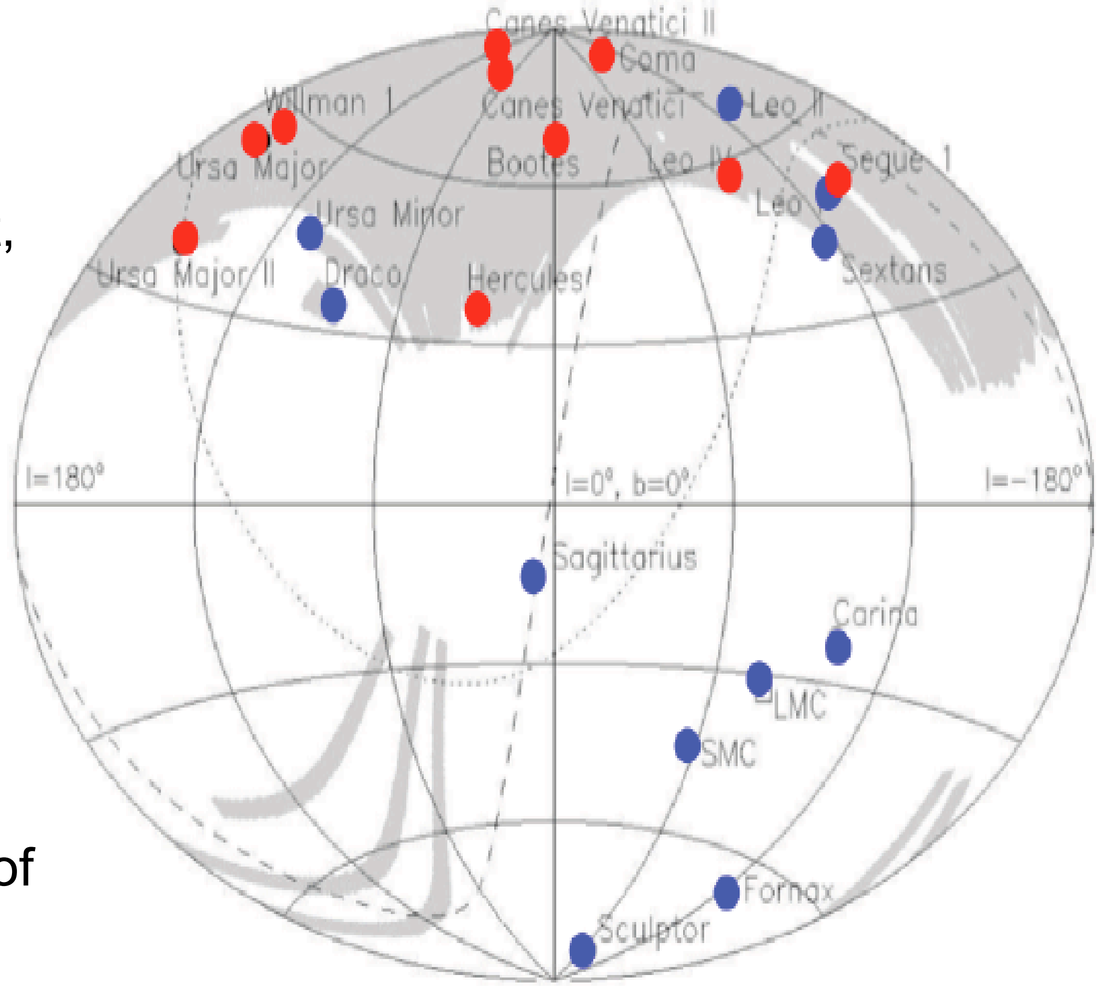
Dwarf Galaxies

- dark matter dominated
- low background: no detected gas, minimal dust, no magnetic fields, little or no recent star formation activity
- lie away from galactic center
- velocity distribution lower than in Milky Way halo: possible Sommerfeld enhancement by an order of magnitude !



Belokurov et al. (2006)

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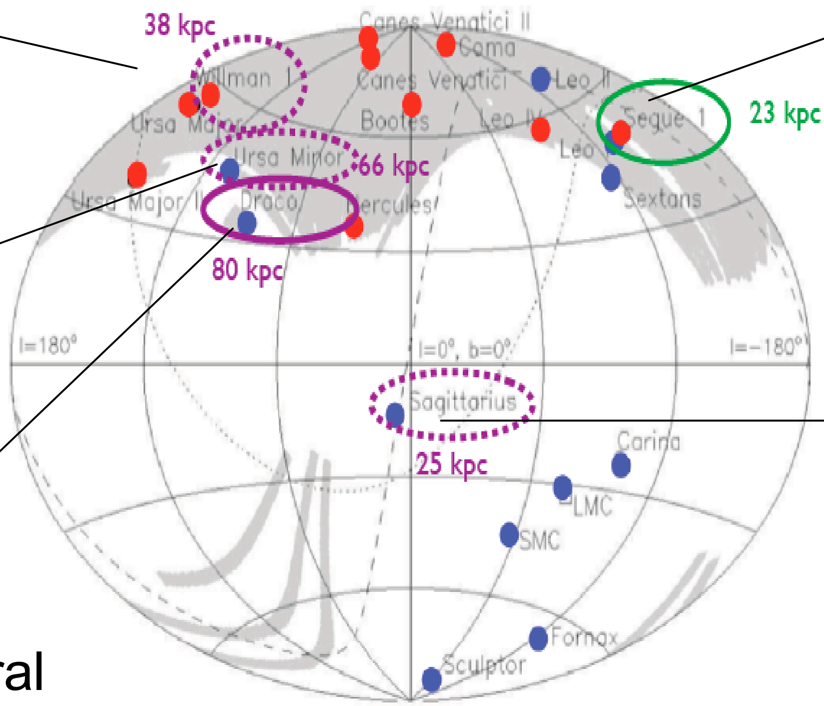
Dwarf Galaxies: Promising Candidates

Willman 1:
Strongest existing constraint

Ursa Minor

Draco:
Observed several times



Segue 1:
recently discovered, very promising candidate

Sagittarius:
direction close to galactic center, being tidally disrupted by the Milky Way

many new dwarfs expected to be discovered in the future.

FSR flux

$$\frac{d\Phi_{FSR}}{dx} = \Phi_0 \left(\frac{\langle\sigma v\rangle}{1pb}\right)\left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)^3 F(x)\ \log\left(\frac{4m_\chi^2(1-x)}{m_l^2}\right)\ J$$

Separates into particle physics factor x astrophysical factor.

F(x): splitting function $F(x) = \frac{1+(1-x)^2}{x}$ $\quad 2\frac{2-x+2x\log x - x^2}{x}$

2-body annihilation 4-body annihilation

J: astrophysical factor. For annihilating dark matter,

$$J = \frac{1}{8.5\ \mathrm{kpc}}\left(\frac{1}{0.3\ \mathrm{GeV/cm^3}}\right)^2 L, \qquad L = \int d\Omega \int_{l.o.s.} \rho^2 dl$$

Dwarf	$\log_{10}(L \times \mathrm{GeV^{-2}cm^5})$
Sagittarius	19.35 ± 1.66
Draco	18.63 ± 0.60
Ursa Minor	18.79 ± 1.26
Willman 1	19.55 ± 0.98
Segue 1	20.17 ± 1.44

R. Essig, N. Sehgal and L. E. Strigari
Phys. Rev. D **80**, 023506 (2009)

For comparison, for the Galactic center with an Einasto profile, the corresponding number is ~ 21 ± 3.

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Atmospheric Cherenkov Telescopes (ACTs)

• Signals from dwarf galaxies expected to be too weak for Fermi LAT to detect: need larger collection areas

⇒ ACTs! (typical effective areas ~10^4 times larger than Fermi)

• typical energy threshold: 200 GeV

• energy resolution: 10-30%

• major disadvantage: large cosmic ray backgrounds (hadronic and leptonic)

• several ACTs currently operational: MAGIC, HESS, VERITAS, CANGAROO

• future telescopes being planned: AGIS, CTA. Will provide an order of magnitude improvement over current instruments.

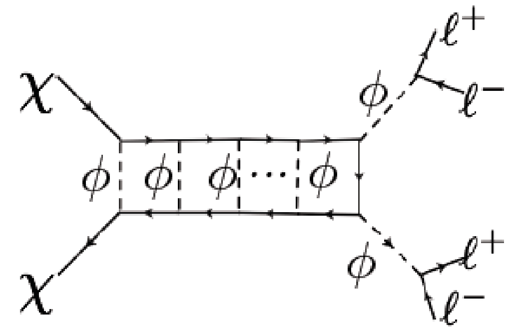
Leptophilic dark matter “models”, favored by current PAMELA, Fermi data.

$\chi\chi \rightarrow \mu+\mu-$

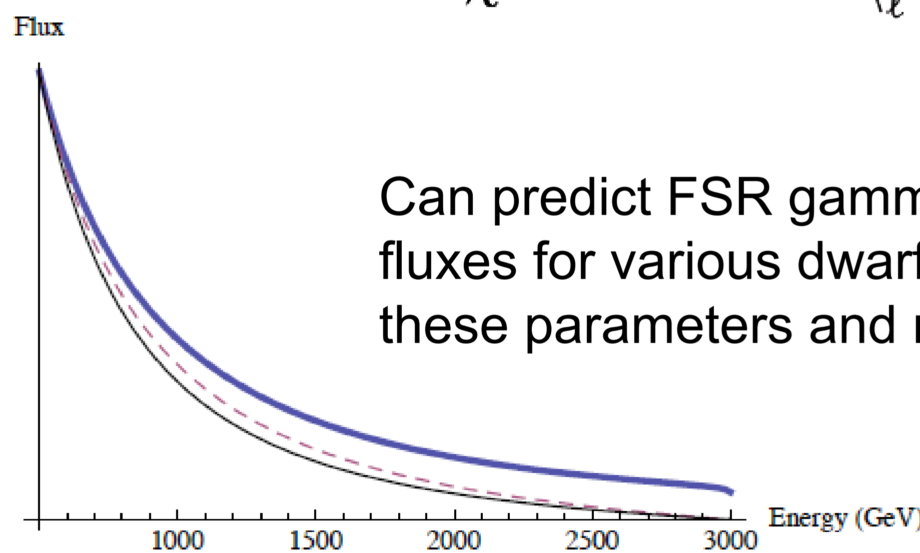
$\chi\chi \rightarrow \phi\phi \rightarrow 4e$

$\chi\chi \rightarrow \phi\phi \rightarrow 4\mu$

ϕ : new, intermediate particle with GeV scale mass, provides Sommerfeld enhancement

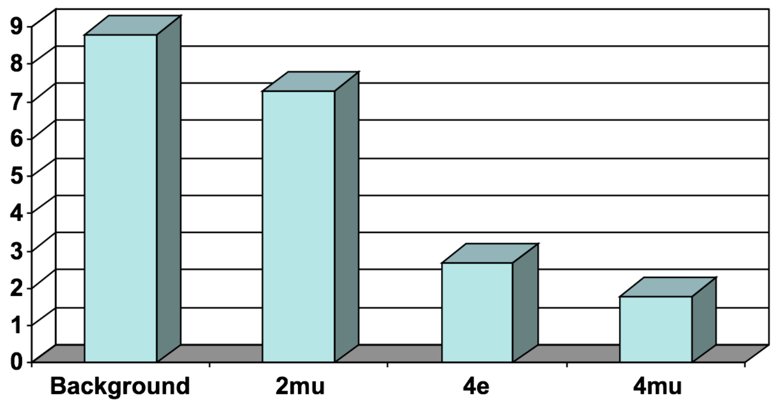


Take
m_χ= 3 TeV,
m_ϕ = 1 GeV
$\langle\sigma_0 v\rangle$ = 3×10^{-23} cm^3s^{-1}



Can predict FSR gamma ray fluxes for various dwarfs for these parameters and models.

Backgrounds



Background and signals fluxes for Segue 1 (in $10^{-12} cm^{-2} s^{-1}$)

- Cosmic ray background: misidentifying hadronic and leptonic events in the atmosphere as gamma ray signals
- Can "subtract" this background away up to statistical fluctuations (ON region - OFF region)

DM backgrounds from inside the galaxy (FSR and invserse Compton scattering) are negligible because of a narrow region of focus and the direction of dwarfs (away from galactic center).

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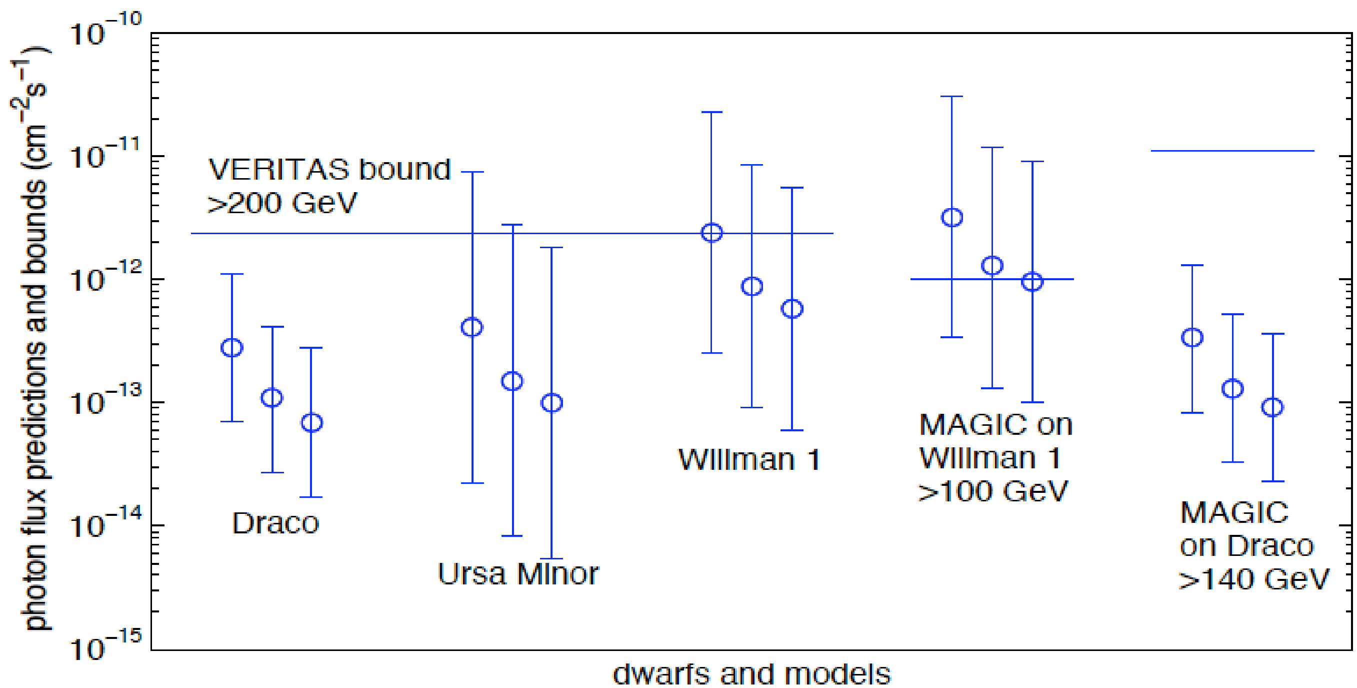
Previous Observations and Upper Bounds

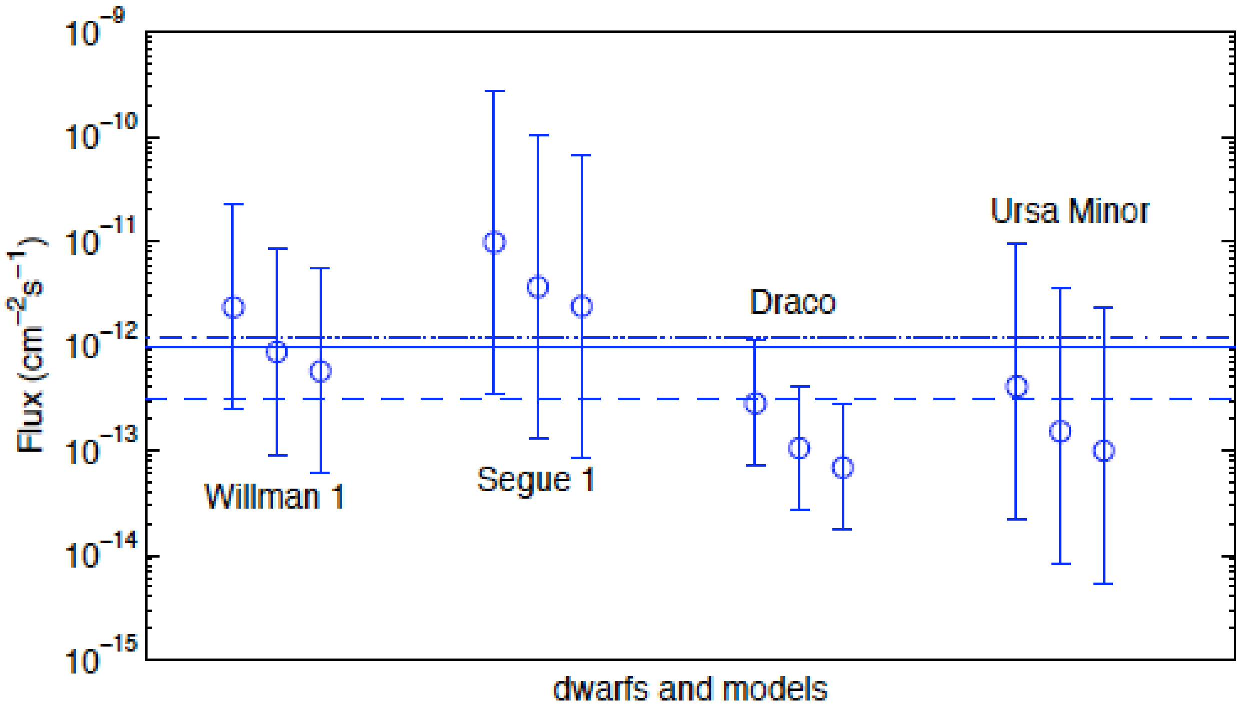
- No significant signals observed

- Large uncertainty in dark matter distribution in all dwarfs, predictions consistent with experimental bounds up to these uncertainties



(Left to right: 2mu, 4e, 4mu predictions for each dwarf)

Detection Prospects



Integrated flux above 200 GeV. Dot-dashed, solid, and dashed lines: 3σ sensitivities of VERITAS, MAGIC, and CTA in 50 hours.

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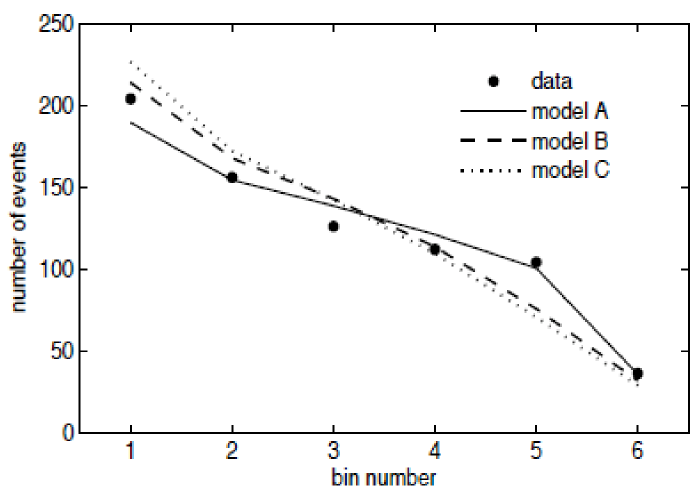
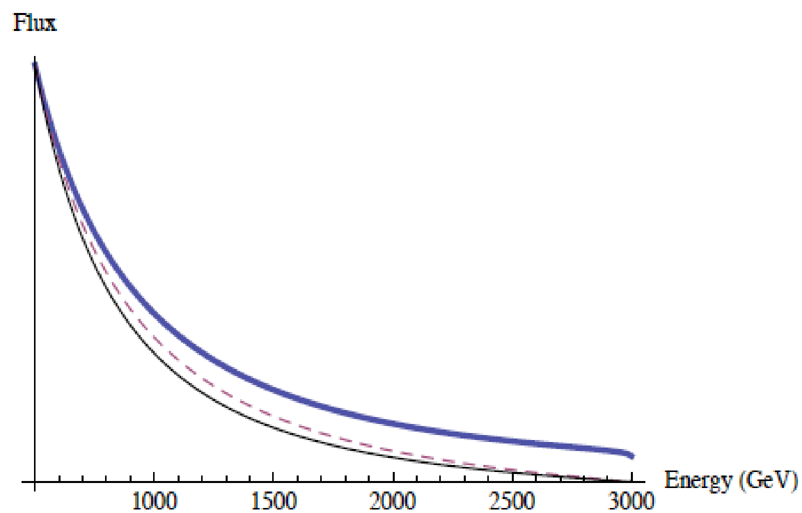
Model Identification

• Once a positive signal is detected, what information can be extracted from it? Can the underlying model and parameters be identified?

• Simulate observation (including background subtraction) and fits to theory for different scenarios:





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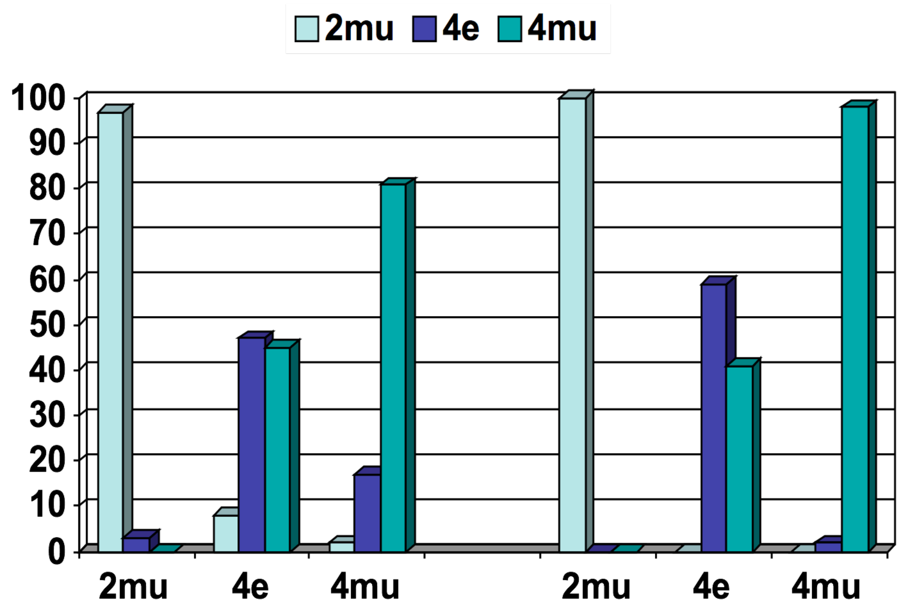
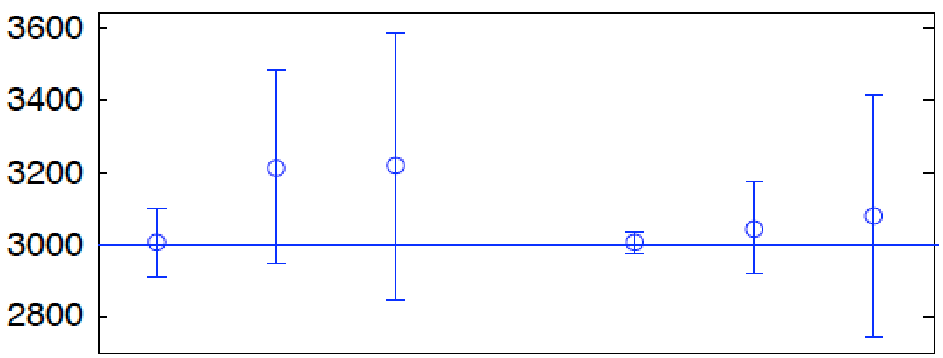
Model Identification
Benchmark case: Observation of Segue 1





Threshold energy: 500 GeV

Top plot: Frequency with which model used to generate data (x-axis) was best fit to the three channels (color coded).

Results for current instrument parameters on left, future parameters on right.

Bottom: best fit masses, in GeV

Overall success rate:
75% for current telescope parameters,
86% for future ones

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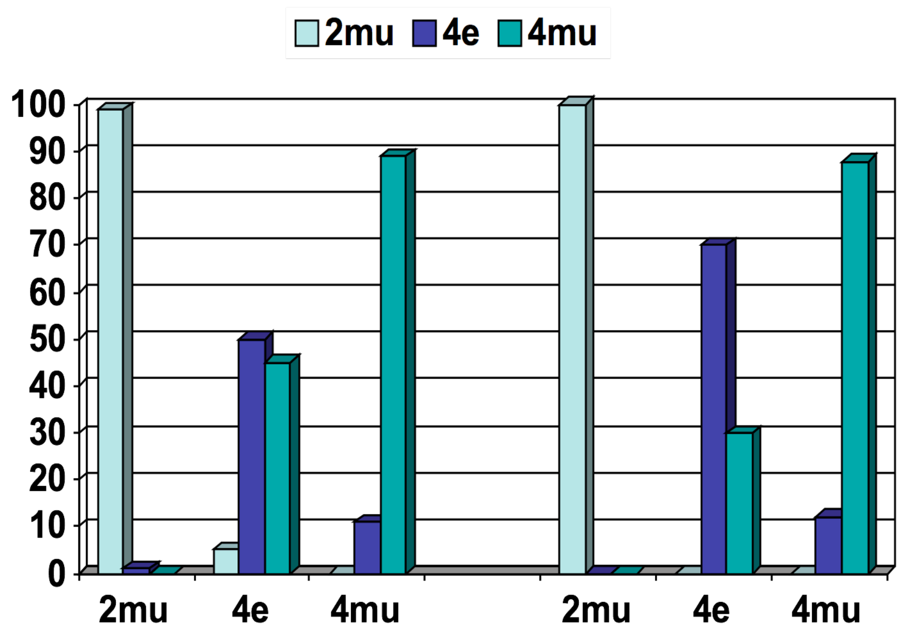
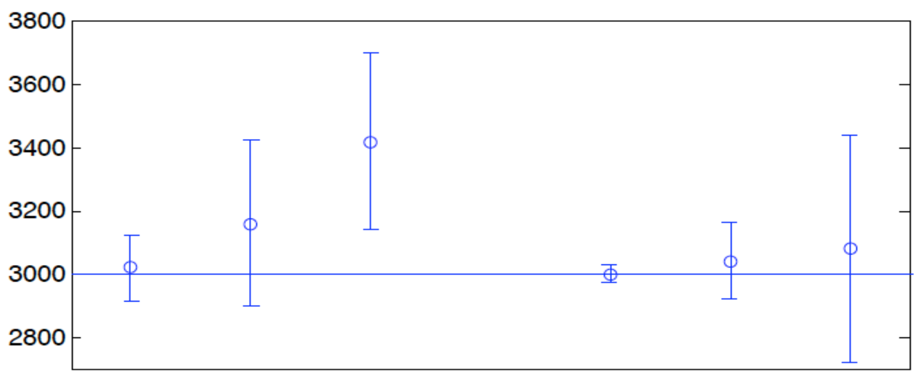
Case 2: A Lower Threshold





Threshold 200 GeV instead of 500 GeV.

More statistics, but background also rises faster than signal at lower energies.

Success rates:
79% (current)
86% (future)

No significant improvement.

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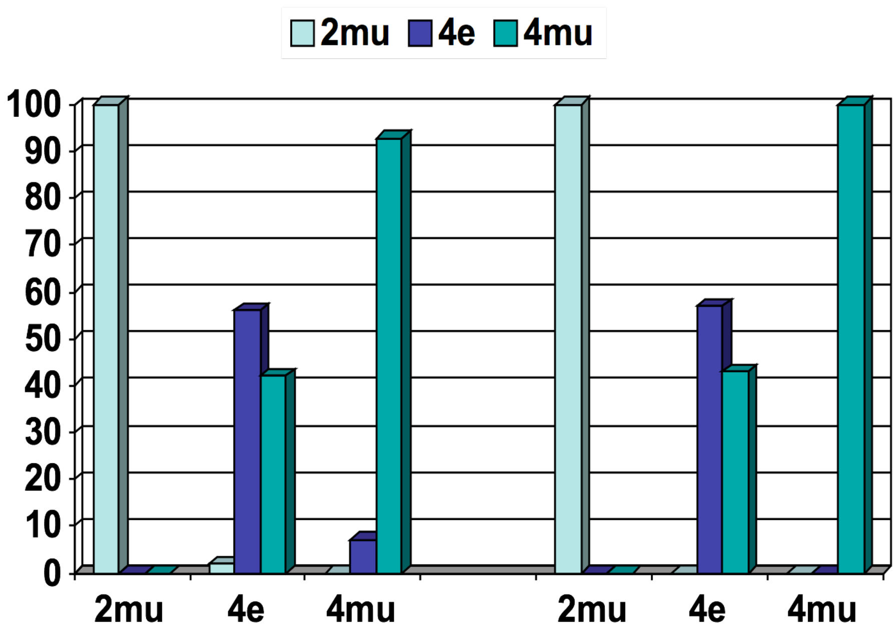
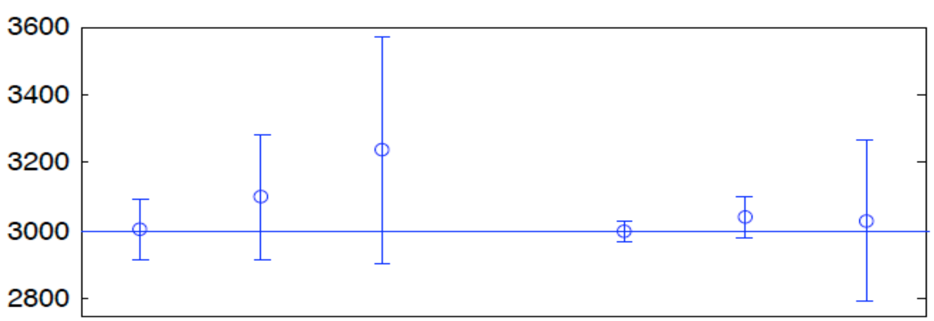
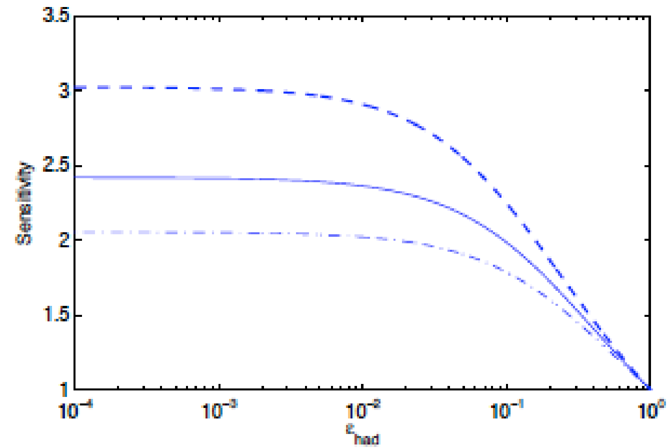
Case 3: Improved Hadron Rejection

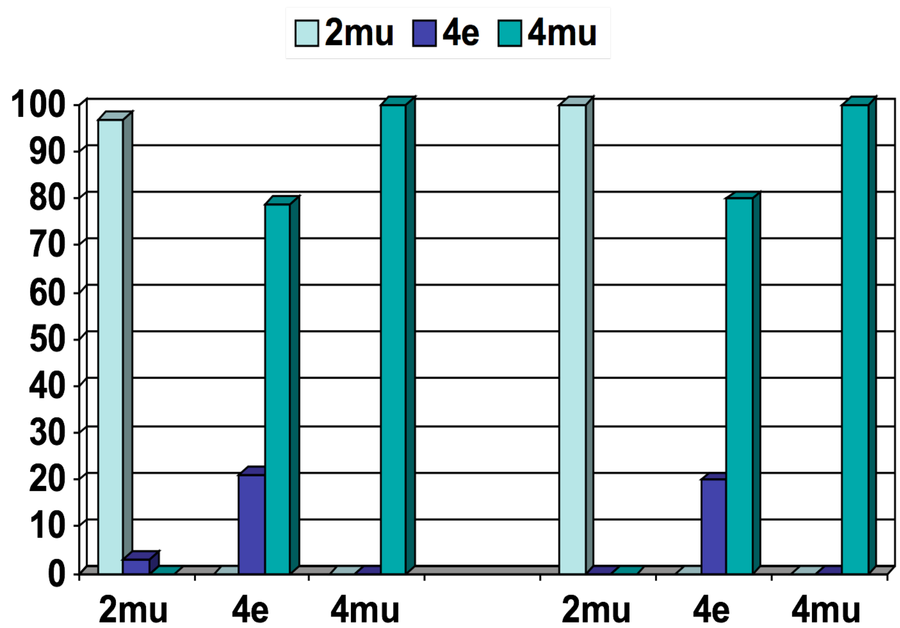


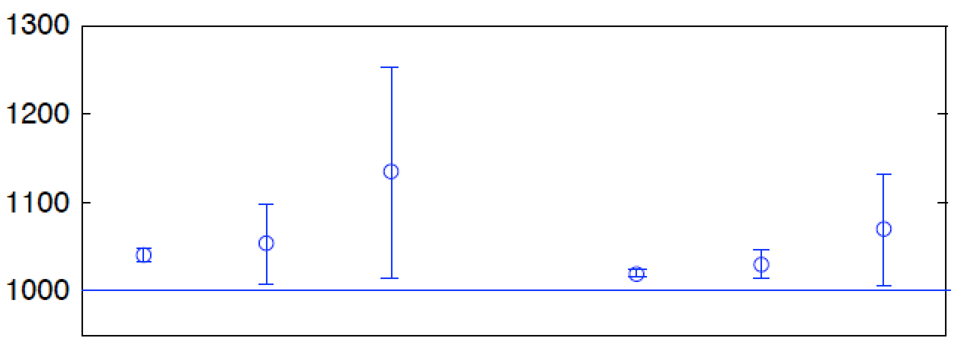




Have been using ε_{had}=1. Try ε_{had}=0.01. Fit quality significantly better, slight improvement in model identification.

Case 4: Lighter dark matter



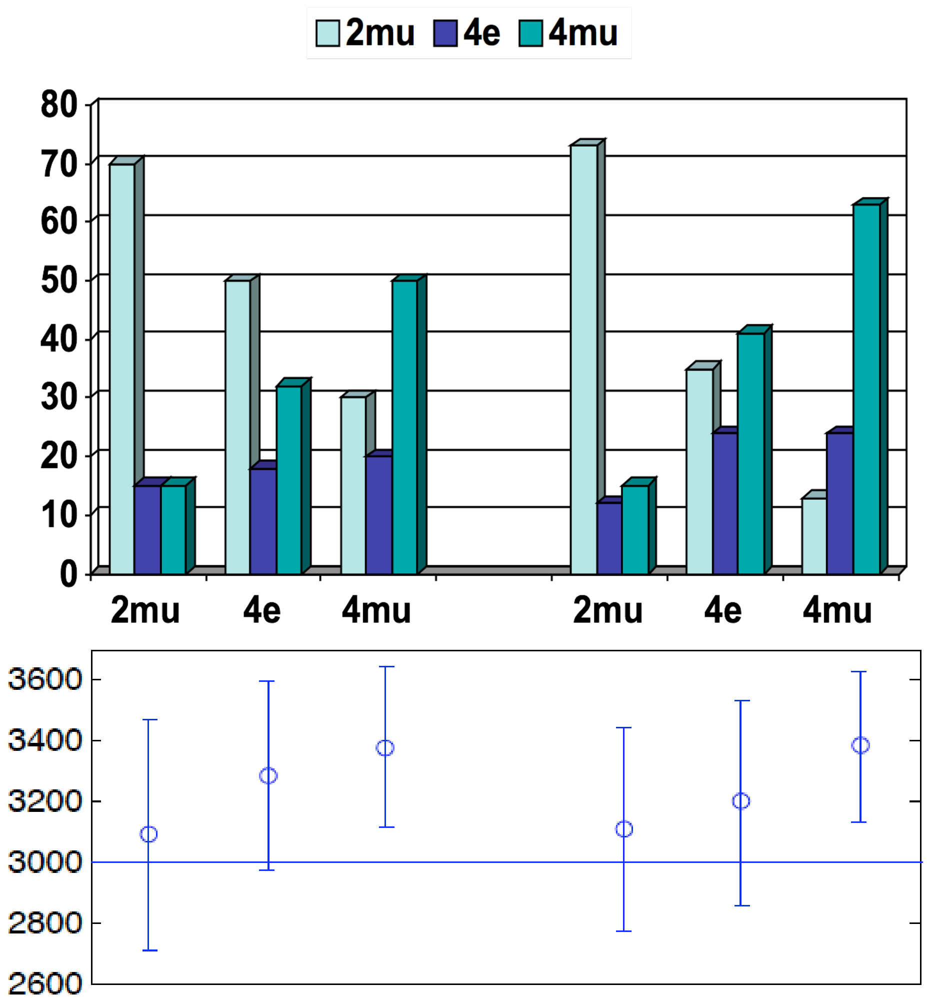


Use m_χ= 1 TeV instead of m_χ= 3 TeV.

Signal has m_χ^{-3} dependence, but will have fewer energy bins.

Fits favor 4mu channel when annihilation is into 4 leptons.

Case 5: 3σ or 5σ detection



Left: 3σ detection
Right: 5σ detection

Success rates now lower:
46% for 3σ, 53% for 5σ

Success rate for discriminating between 2 and 4 body channels:
63% and 75% respectively.

Summary

• Prospects of indirect detection of dark matter via FSR from dwarf galaxies using current and near-future ACTs are excellent.

• Large uncertainty in distribution of dark matter in dwarf galaxies.

• Segue 1 is an extremely promising candidate.

• Fits to observed signals can identify the dark matter mass to ~10-20% accuracy, and correctly identify the annihiation channel with ~60-80% probability.

•Success rate for model identification is robust with respect to changes in energy threshold, WIMP mass, energy resolution, and hadron rejection capabilities.

"When is science going to explain the dark matter
I find in my belly button every morning?"

?

Questions