Fermi
Gamma-ray Space Telescope

Dark Matter Observations and Fermi

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3rd Fermi Symposium
Roma, May 9-12 2011
I – Basics of Indirect DM Searches

Spectra
Fluxes
Targets
The so-called WIMP *miracle*
- most natural extension of particle physics Standard Model provide a natural DM candidate with correct relic density from cosmology

Thermal freeze-out gives benchmark annihilation cross-section $\langle \sigma v \rangle \sim 3 \times 10^{-26}$ cm$^3$s$^{-1}$
Choice of the particle physics model fixes final states and spectrum, but in general

- Non simple power law spectra
- $b$-$b\bar{b}$ spectrum good proxy for hadronic channels (quarks and gauge bosons)
- Leptonic channels in conjunction with CRE excesses
- Inclusive photon spectra

Smoking-gun signature, but $O(10^{-3} / 10^{-4})$ suppressed
- Measured flux (from the instrument)
  - Instrument related systematics
- Expected flux typically factorized as

\[
\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \phi, \theta) = \frac{1}{4\pi} \frac{\langle \sigma_{\text{ann}}vn \rangle}{2m_{\text{WIMP}}^2} \sum_f \frac{dN_{\gamma f}}{dE_\gamma} B_f \times \int_{\Delta \Omega(\phi, \theta)} d\Omega' \int_{\text{los}} \rho^2(r(l, \phi')) dl(r, \phi')
\]

- Particle Physics factor (from theorists)
  - Model-dependent
- DM density (from measurements and simulations)
  - Large uncertainties
  - Folds with instrument resolution (source extension)
Basics – DM targets in the sky

Satellites
Low background and good source id, but low statistics, in some cases astrophysical background

Galactic Center
Good Statistics but source confusion/diffuse background

Milky Way Halo
Large statistics but diffuse background

Spectral Lines
No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Extra-galactic
Large statistics, but astrophysics, galactic diffuse background

Galaxy Clusters
Low background, but low statistics
II – Observation techniques and example results

Cosmic Rays
Neutrinos
Gamma-rays from the ground
Gamma-rays from space
Spectrometers (PAMELA, AMS, balloons)
- Measure particle ID, charge
Calorimeters (ATIC, Fermi, HESS, balloons)
- Separate EM from hadronic signals via shower topology
Statistics driven by $\sim$size (acceptance), integrated livetime
Inclusive spectrum
- Hard with no strong features (Fermi)
- $\sim>$ TeV cutoff (HESS)

CRE Anisotropies (Fermi)
- $\sim$Exclude single local astrophysical source (dipole)
- Leave room for DM (expected more symmetrical halo)
- Same technique used to constrain CREs from the Sun and derive DM limits (see poster DMNP.S1.N8)
- Positron fraction (Pamela, Fermi)
  - Rising
  - At odd with standard production of secondaries (and anti-proton spectrum from Pamela)
- Electron spectrum (Pamela)
  - Consistent with Fermi
- Leptophilic DM ?
  - Test with gamma-rays!
Workhorse IC muon neutrino tracking
  - ~degree resolution

Search for large scale anisotropy form DM in the Galactic Halo
  - ON-region (signal) centered around GC
  - OFF-region (background) anti-centered on the GC
  - Galactic center outside FOV (looks at events below horizon from Northern sky)

arxiv 1101.3349, ~5k events

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Sensitive to high energy
- Limits to WIMP annihilation cross-section derived similarly to gamma-ray analysis
- \( \sim O(10^4) \) from thermal limit, expected improvements from
  - Increased acceptance (IceCube40)
  - other targets (dwarfs, GC with IceCube core)

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- \( \sim 10^4 \text{ m}^2 \) effective area
  - atmosphere, wide mirrors
- \( \sim 0.1^\circ \) angular resolution
- \( \sim 100 \text{ GeV} \) current WIMP threshold
- Field of view (few degrees) and duty cycle current challenge
  - Competition with astrophysical targets
  - Typical observing time for DM targets \( \sim 30 \text{ hrs} \)
γ-rays from ground – some results

- Limits on single dwarfs
  - \( \sim O(10^4) \) above thermal limit
  - Significant improvement could come from much improved sensitivity of CTA

- Extended regions (Galactic Halo)
  - Work in progress at HESS

MAGIC, arxiv 1103.0477 and poster DMNP.S1.N6

Galactic center analyses
- help resolving sources in the region
- VERITAS detects GC (confirms HESS/MAGIC spectra) with large zenith angle observations
- DM constraints requires careful definition of ON and OFF regions
- HESS constraints $\sim O(10) \times <\sigma v>_{\text{thermal}}$ but insensitive to isothermal DM profiles

Beilke, this Symposium

H.E.S.S., arXiv:1103.3266
Key features for DM searches

- Energy range and resolution
  - probe $\sim$GeV – 1 TeV WIMPs with $7 < \sigma_E < 15\%$
- $\sim 0.1^\circ$ angular resolution
  - From point source to diffuse emission
- Full-sky coverage
  - All targets at same time
    - Synergy with astrophysics (e.g. diffuse gamma-rays)
    - No competition for observing time with astrophysical program
- Large photon statistics
Search for gamma-ray emission from dwarf spheroidals
- No astrophysical emission expected

Conventional Fermi-LAT point source analysis
- uses LAT experience in handling instrument response and background

Convert flux Upper Limits to model-dependent UL on DM annihilation cross section
- Uncertainties on J factor

Updated results from stacked dwarfs reach $\sim <\sigma v>_{\text{thermal}}$
- See talk by Llena-Garde
Search for gamma-ray lines in inclusive, all-sky spectrum
- No astrophysical background

Suppressed signal
- limits still some $\sim O(1)$ X thermal WIMPs
- Some scenarios constrained (non thermal WIMPs)

Require good and well-known energy resolution
- See talk by Bloom

update to PRL 104, 091302, 2010

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Search for anisotropies of diffuse gammas through Angular Power Spectrum

Benefits from LAT full sky coverage, uniform exposure, angular resolution

Potential to reveal unmodeled source classes, including Dark Matter
  - See talk by Siegal-Gaskins
  - See poster by Fornasa (DMNP.S1.N5)
III - Updates from Fermi and caveats

Point sources and DM distribution
Extended regions and diffuse emission
Isotropic and astrophysical contributions
Fermi updates on sources

- No DM satellites found in 1 year of data when requiring
  - Spectrum inconsistent with conventional power law
  - Source extension (almost all pulsars pass simple spectral tests)

- Galaxy Clusters
  - Stacking method improved limits
  - Guaranteed gamma-ray from CR interactions
  - See talk by Zimmer

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III Fermi Symposium,
- Important for converting flux UL into cross-section limits
- J factor
  - Important for dSph
- Diffusion
  - Impact IC component for leptonic final states
- Role of substructures
  - Expected from theoretical arguments
  - can be used to boost signal and improve limits
Exploits both spectral and spatial information
- Data binned in E and angle

Large residuals in the fit favor a DM component
- scan model parameters of diffuse emission that affect more significantly DM limits
- Compute limits assuming all diffuse emission is DM

Simultaneously fit CR and gamma-ray data scanning full phase space of CR models

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Residual maps from a selection of GALPROP models show considerable large scale structures
- Fermi lobes, Loop I, bubbles ...
see talk by JM Casandjian

Su, Slayter and Finkbeiner, 2010
Fermi updates – Isotropic gamma-ray Background

- All sky spectrum
  - Clean sample to extend beyond 100 GeV and probable 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)
  - See 2010, JCAP, 04, 014
Wealth of results from Indirect Dark Matter searches

- Cosmic Rays
  - Fermi and Pamela provide coherent observational picture

- Neutrinos
  - Initial results, comprehensive observational program

- Gamma-rays
  - Fermi and IACT complementary in energy range

Important synergies

- Gamma-ray results disfavor lepto-philic DM from CRE excesses
- Hints from direct or accelerator searches reduce models phase space for cross-checks
Gamma-ray results

- Point sources cleanest target
  - Fermi limits from dwarfs scratching WIMP benchmark thermal cross section at \( \sim 10 \) GeV
- All sky (EGB, line, anisotropies) accessible to Fermi only
  - Focus on instrument performance
- Extended regions (halo, Inner Galaxy) promising but hard
  - Diffuse emission is the maximal uncertainty, need input from Fermi and other missions to improve modeling