Stefano Profumo
UC Santa Cruz
Santa Cruz Institute for Particle Physics
T.A.S.C. [Theoretical Astrophysics in Santa Cruz]

Fundamental Physics from the Sky

*Latest News on Indirect Dark Matter Detection*

“Shedding Light on the Nature of Dark Matter”
Keck Institute for Space Studies
Pasadena, July 13-24, 2009
WIMPs pair-annihilate to stable, SM particles

“Indirect” Dark Matter Detection

Can we do fundamental physics with indirect DM detection?

✓ Multi-messenger endeavor
✓ Fight (understand) astrophysical backgrounds!
Indirect Detection: Latest News

**WMAP Haze – Planck in orbit!**

**Fermi-LAT: GeV excess**

**ATIC: e+e- anomaly**

**Fermi-LAT: γ-ray limits from local dwarfs and galaxy clusters**

**Pamela: positron fraction**

**Fermi-LAT: e+e-**

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**Fermi-LAT: e+e-**
Old “conventional” CRE Model
\[ \gamma_0 = 2.54 \]

New “conventional” CRE models
\[ \gamma_0 = 2.42 \quad \gamma_0 = 2.33 \]

Spectrum well reproduced by Diffuse Galactic Cosmic-Ray Model, with harder injection spectral index \( \gamma_0 \) than in previous CR models

[electrons accelerated by continuously distributed astrophysical sources, e.g. Supernova Remnants]
Simulations of what Fermi would have seen is the ATIC feature was there.

The ATIC anomalous bump is not confirmed!!

Tremendous jump in statistics

[ATIC counts above 100 GeV: 1,724, PPB-BETS: 84, Fermi-LAT: 233,409 (ATIC x 137)]
Is there a residual "anomalous spectral feature" in the Fermi data?

Most probably **NO**: in the ~ TeV range

- CR Source Spectrum **Cutoff**
- Diffusion **Radius** comparable to mean SNR separation → source **stochasticity** effects! [breakdown of spatial continuity and steady-state hypotheses]
**Harder** (larger flux at high energy) $\text{e}^+ \text{ e}^-$ spectrum
→ **steeper** secondary-to-primary positron fraction ratio

\[
\frac{e^+}{e^+ + e^-} \propto \frac{E^{\gamma_{\text{protons}} + \gamma_0 - \delta}}{}
\]
Fermi CRE data exacerbates the discrepancy between a purely secondary diffuse cosmic-ray origin for positrons and the positron fraction measured by Pamela.

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New “conventional” CRE models

Old “conventional” CRE Model
New Fermi-LAT Data: $\gamma_{\text{local}} = 3.045 \pm 0.008$

- No problem at **low energies** (both propagation and solar modulation)
- **Real troubles** at **high energies**: no way to fit with the hard $e^+e^-$ Fermi data!!

Delahaye et al (2008) [0809.5268]
Fermi’s precise measurement of a hard ($\sim E^{-3}$) CRE spectrum implies that one or more additional positron sources are conclusively needed to explain the Pamela positron fraction data.
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Example of fit to both Fermi and Pamela data with known (ATNF catalogue) nearby, mature pulsars and with a single, nominal choice for the e+/e- injection parameters

\[ \Gamma = 1.7 \quad E_{\text{cut}} = 1100 \ \text{GeV}, \]
\[ \eta_{e^\pm} = 40\% \quad \Delta t = 6 \times 10^4 \ \text{yr}. \]

Grasso, Profumo, Strong et al., 0905.0636
What if we randomly vary the pulsar parameters relevant for e+e- production?

[injection spectrum, e+e- production efficiency, PWN “trapping” time]
What if we randomly vary the **pulsar parameters** relevant for **e+e- production**?

*injection spectrum, e+e- production efficiency, PWN “trapping” time*

Grasso, Profumo, Strong et al., 0905.0636

\[
1.5 < \Gamma < 2.0, \quad 800 < E_{\text{cut}} < 1400 \text{ GeV},
\]

\[
10 < \eta_{e^\pm} < 30 \%, \quad 5 < (\Delta t/10^4 \text{ yr}) < 10.
\]
What if we randomly vary the **pulsar parameters** relevant for **e+e- production**?

*injection spectrum, e+e- production efficiency, PWN “trapping” time*

Under reasonable assumptions, electron/positron **emission** from **pulsars** offers a **viable interpretation** of **Fermi** CRE data which is also **consistent** with the **HESS** and **Pamela** results

Grasso, Profumo, Strong et al., 0905.0636
Dark matter interpretation: quite a bit of interest

positrons and electrons originate from the annihilation or decay of particle dark matter (for a possibly incomplete list of related studies appeared before the first version of the present manuscript was released see Ref. [39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85]; further studies appeared between the first and the present version of this manuscript include [86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137]). As opposed to all of the other possibilities mentioned above, a dark matter interpretation invokes an entity whose fundamental particle physics nature has yet to be unveiled, and whose

Profumo, “Dissecting Pamela (and ATIC) with Occam’s Razor…”, 0812.4457
An expected outcome of Redman’s Theorem

“Any competent theoretician can fit any given theory to any given set of facts” (*)

(*) Quoted in M. Longair’s “High Energy Astrophysics”, sec 2.5.1 “The psychology of astronomers and astrophysicists”

Roderick O. Redman (b. 1905, d. 1975) Professor of Astronomy at Cambridge University
1. Much weaker rationale to postulate a **DM mass** in the 0.3-1 TeV range (“ATIC bump”) motivated by the CR electron+positron spectrum

2. If the Pamela positron excess is from DM annihilation or decay, Fermi CRE data set **stringent constraints** on such interpretation

3. Even neglecting Pamela, Fermi CRE data are useful to put **limits** on rates for particle **DM annihilation** or **decay**

4. We find that a **DM interpretation** to the **Pamela** positron fraction data consistent with the new **Fermi-LAT CRE** is a **viable** possibility
Examples of (poor man’s) Dark Matter models that fit the Fermi data

Grasso, Profumo, Strong et al., 0905.0636
More examples of **Dark Matter** models that also fits the Fermi/Pamela data

(from Bergstrom et al, 2009)
Role of **Fermi** to assess the **origin** of high-energy CRE:

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3. Discovery and improved understanding of **gamma-ray pulsars**
New radio-quiet **gamma-ray pulsars** can play a decisive role!

Fermi-LAT Pulsar **Blind search** at UC Santa Cruz (including the “**slug**” pulsar)
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4. **Constraints** on **DM** interpretation with **gamma-ray** data (e.g. nearby clump)
If a **nearby DM clump** is the source of the e+e- excess, Fermi-LAT will detect a **gamma-ray** signal from it!!
Best-case scenarios constrained via **multi-wavelength** observations

**Conservative Constraints:**
- No Astrophysical EG Background included (**blazars**)  
- IC off of **CMB** only (no starlight, UV, IR)  
- No **low-velocity** enhancements

Extra-galactic **all-redshift, all-halos** emission, including IC off CMB

Profumo and Jeltema, JCAP (2009), arXiv:0906.0001
Role of Fermi to assess the origin of high-energy CRE:

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2. Local CRE source? \(\rightarrow\) Compare the Inverse Compton and Bremss. emis. predicted from the measured CRE spectrum with diffuse gamma-ray data

3. Discovery and improved understanding of gamma-ray pulsars

4. Constraints on DM interpretation with gamma-ray data (e.g. nearby clump)

5. Anisotropy: search for excess CRE from bright nearby pulsars
Predicted **Anisotropy** for selected Pulsars

- Problem: pulsar *proper motion* !!
- Also ongoing: **East-West** asymmetry search

Profumo, 0812.4457
Fermi CRE data indicate a hard high-energy CRE spectrum ($\Phi \sim E^{-3}$).

Data perfectly compatible with Diffuse Galactic Cosmic Ray origin, but, including Pamela data, a purely secondary diffuse CR origin for the positron excess is extremely unlikely.

Pulsars are strong candidates as primary electron/positron sources.

Dark Matter annihilation/decay is constrained but not ruled out by Fermi data as possible primary high-energy positron-electron source.