Tracking Quintessence, WIMP Relic Density, PAMELA and Fermi LAT

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Based on:

- S. Lola, C.P. and E. Tzelati, arxiv:0907.2941;
- C.P, *Work in Progress*

Outline

CMB and SNIe Observational Data

The Accurate Determination of Cosmological Parameters by WMAP5 Establishes Convincing Evidence for the Constitution of the Universe:

$$\Omega_{\rm CDM} = 0.214 \pm 0.027, \quad \Omega_{\rm DE} = 0.74 \pm 0.12 \quad \text{and} \quad w_{\rm DE} < -0.86.$$

- Natural Candidates to Account for the CDM are the *Weakly Interacting Massive Particles* (WIMPs), χ. We Require:

$$0.097 \lesssim \Omega_\chi h^2 \lesssim 0.12 \quad \text{Where} \quad \Omega_\chi h^2 = f\left(m_\chi, \langle\sigma v\rangle\right) \quad \text{Within the Standard Cosmology (SC).}$$

  (m_χ is the χ Mass and $\langle\sigma v\rangle$ is the Thermal-Averaged Cross Section of χ Times Its Velocity).

- DE can be Explained With the Introduction of a Slowly Evolving Today Scalar Field, q, Called Quintessence[1]. An Open Possibility in This Scenario is the Existence of an Early *Kination Dominated* (KD)[2] era.

Impact of KD Era on $\Omega_\chi h^2$

- The Presence of a KD Era Increases[3] Drastically (up to 3 Orders of Magnitude) $\Omega_\chi h^2$.

$$\Omega_\chi h^2 = f\left(m_\chi, \langle\sigma v\rangle, \ \text{Quintessential Parameters}\right).$$

- As a Consequence, $\langle\sigma v\rangle$'s Larger Than Those Allowed in SC are Required in a *Quintessential Kination Scenario* (QKS). I.e,

$$0.097 \lesssim \Omega_\chi h^2 \lesssim 0.12 \quad \Rightarrow \quad \begin{cases} \langle\sigma v\rangle \sim 2\cdot 10^{-9}\ \text{GeV}^{-2}, & \text{in the SC,} \\ \langle\sigma v\rangle \sim (10^{-7} - 10^{-6})\ \text{GeV}^{-2}, & \text{in the QKS} \end{cases} \quad \text{for} \quad m_\chi \sim (0.1 - 1)\ \text{TeV}.$$

[1] *R.R. Caldwell et al. (1997)*

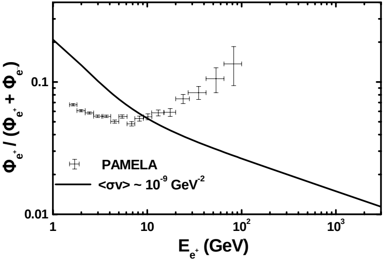
[2] *B. Spokoiny (1993); M. Joyce (1997)*

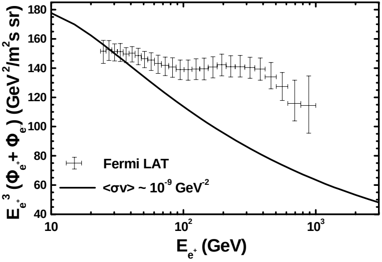
[3] *P. Salati (2002); S. Profumo and P. Ullio (2003); C.P. (2005).*

Observations on the $e^{\pm}$-*Cosmic Ray* (CR) Fluxes

Recently PAMELA[4] and Fermi LAT[5] Have Reported (Confirming, More Or Less, Previous Experiments[6]) A Rise of:

- e^+ Flux Fraction for $10 \lesssim E_{e^+}/\mathrm{GeV} \lesssim 100$
- In the Total $e^+ + e^-$ Flux for $0.3 \lesssim E_{e^+}/\mathrm{TeV} \lesssim 0.8$





- PAMELA Reports No Excess on $\bar{p}$-CR Fluxes[4]. Therefore $\chi\chi \to l^+ l^-$, With $l = e,\ \mu$ ($l = \tau$ is Excluded from BBN).

Is Possible an Explanation of the $e^{\pm}$-CR Anomalies Via χ Annihilation in the Galaxy?

- It is not Possible within SC due to the Very Low $\langle\sigma v\rangle$ Required from the CDM Considerations
- Is it Possible in the Context of an Attractive Quintessential Scenario?

[4] *PAMELA Collaboration (2009)*

[5] *The Fermi-LAT Collaboration (2009))*

[6] *ATIC Collaboration (2008); AMS-01 Collaboration (2007); HEAT Collaboration (1997).*

Relevant Equations

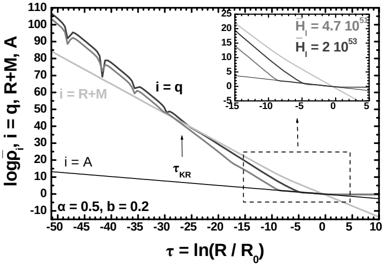
We Assume the Existence of a Spatially Homogenous Scalar Field, q Which Obeys the Equation: $\ddot{q} + 3H\dot{q} + dV/dq = 0$, Where

$$V = \frac{M^{4+a}}{q^a} + \frac{b}{2}H^2q^2,$$ with Free Parameters $a, b,$ and M and Initial Conditions $\bar{q}_{\rm I} = \bar{q}(\tau_{\rm I}) = 0.01$, $\bar{H}_{\rm I} = \bar{H}(\tau_{\rm I}) = \sqrt{\bar{\rho}_{q{\rm I}}}$.

- Normalized Quantities: $\bar{\rho}_i = \rho_i/\rho_{\rm c0}$ With $i = q$, R, M and $\rho_{\rm c0} = 3m_{\rm P}^2H_0^2$. Also $\bar{q} = q/\sqrt{3}m_{\rm P}$ and $\bar{H} = H/H_0$.
- $\bar{H}^2 = \bar{\rho}_q + \bar{\rho}_{\rm R} + \bar{\rho}_{\rm M}$ Where $\bar{\rho}_{\rm R} \simeq \bar{\rho}_{\rm R0}e^{-4\tau}$, $\bar{\rho}_{\rm M} = \bar{\rho}_{\rm M0}e^{-3\tau}$ and $\bar{\rho}_q = \bar{Q}^2/2 + V$ With $\bar{Q} = \bar{H}d\bar{q}/d\tau$ and $\tau = \ln(R/R_0)$.
- Extracted Quantities:
  - The Density Parameters, $\Omega_i = \rho_i/(\rho_q + \rho_{\rm R} + \rho_{\rm M})$, $i = q$, R, M,
  - The Barotropic Index, $w_q = (\dot{q}^2/2 - V)/(\dot{q}^2/2 + V)$

The Cosmological Evolution

The Field q Undergoes Four Phases During its Cosmological Evolution:



- The KD Phase With $\dot{q} \gg \rho_{\rm R} \gg V$. Therefore $\bar{H} \simeq \bar{H}\bar{q}'/\sqrt{2 - b\bar{q}^2}$,

$$\bar{q} \simeq \sqrt{\frac{2}{b}}\sin\sqrt{b}\,(\tau - \tau_{\rm I}) \;\Rightarrow\; \tau_{\rm ext} \simeq (2k+1)\sqrt{\frac{1}{b}}\,\frac{\pi}{2} + \tau_{\rm I},\;\; k = 0, 1, 2, ...$$

  For $\tau = \tau_{\rm ext}$, $\dot{q} = Hdq/d\tau = 0$ Instantaneously and so, $\rho_{\rm R} > \dot{q}/2$. Consequently, the q Oscillations Become Anharmonic.

- Frozen-Field Dominated Phase, Where $\bar{H}^2 \simeq \bar{\rho}_{\rm R}$ and $\bar{q} = {\rm cst}$.
- Attractor Dominated Phase, Where $\rho_q \simeq V$ and $\bar{H}^2 \simeq \bar{\rho}_{\rm M}$. $\bar{\rho}_q$ Admits a Tracking Solution

$$\bar{\rho}_{\rm A} \simeq \bar{\rho}_{\rm Af}\exp\left(-3(1 + w_q^{\rm fp})\tau\right) \;\text{ with }\; w_q^{\rm fp} = -2/(a+2)$$

- Vacuum Dominated Phase Where $\bar{H} \simeq \bar{\rho}_q = V$.

Imposed Requirements

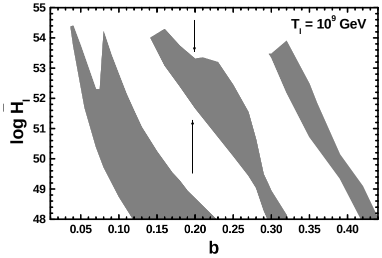
- The Constraint of the Initial Domination of Kination: $0.5 < \Omega_q(\tau_I) \leq 1$.
- The Inflationary Constraint: $P_t/P_s \lesssim 1 \Rightarrow \bar{H}_I \leq 10^{56}$, Where P_t $[P_s]$: the Power Spectrum of the Tensor [Scalar] Perturbations.
- The BBN Constraint: $\Omega_q^{BBN} \leq 0.21$.
- The DE and Coincidence Constraint: $\Omega_q(0) = \Omega_{DE} = 0.74 \Rightarrow M \sim 1$ eV and $d^2V(\tau=0)/dq^2 \simeq H_0^2$.
- The Cosmic Acceleration Constraint[9]: $-1 \leq w_q(0) \leq -0.86 \Rightarrow a \leq 0.6$.

$b > 0$ Ensures The Coexistence[7] Of The Early KD Phase With The Tracking Solution[8]

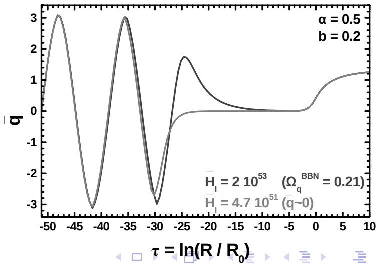
[7] A. Masiero et al. (1999); F. Rosati (2003).
[8] P. Binetruy (1999).
[9] C. Baccigalupi et al. (2002).

The Band Structure of the Allowed Parameter space

Imposing the Observational Constraints we Obtain the Following Allowed Region In the $b - \log\bar{H}_I$ Plane



The Band Structure of the Allowed Area Can be Explained From The Following Plot in the $\tau - \bar{q}$ Plane



Calculating $\Omega_\chi h^2$

The Number Density, n_χ, of χ's Satisfies the Following *Boltzmann Equation* (BE):

$$\left.\begin{array}{l}\dot{n}_\chi + 3Hn_\chi + \langle\sigma v\rangle\left(n_\chi^2 - n_\chi^{\rm eq2}\right) = 0\\ \text{We Define } Y_\chi = n_\chi/s \text{ and } Y_\chi^{\rm eq} = n_\chi^{\rm eq}/s\end{array}\right\} \Rightarrow Y_\chi' = -y\sqrt{\frac{g_b}{g_q}}\overline{\langle\sigma v\rangle}\left(Y_\chi^2 - Y_\chi^{\rm eq2}\right) \text{ Where } {}' = \frac{d}{d\tau},\; y(\tau) = \frac{\bar{s}}{\sqrt{\bar\rho_{\rm R}}}$$

$$\bar{s} = \frac{s}{\rho_{\rm c0}^{3/4}},\; \overline{\langle\sigma v\rangle} = \sqrt{3}m_{\rm P}\,\rho_{\rm c0}^{1/4}\langle\sigma v\rangle,\; \bar{H} \simeq \sqrt{\frac{g_q}{g_b}\bar\rho_{\rm R}},\; \text{With } g_b = 1 - \frac{b}{2}\bar{q}^2 \text{ And } g_q \simeq \begin{cases}1 + \bar{Q}^2/2\bar\rho_{\rm R} & \text{for } \tau \ll \tau_{\rm KR},\\ 1 & \text{for } \tau \gg \tau_{\rm KR}.\end{cases}$$

$$\text{Also } Y_\chi^{\rm eq}(x) = \frac{45g}{4\pi^4}\sqrt{\frac{\pi}{2}}\frac{g}{g_{s*}}\,x^{-3/2}\,e^{-1/x}P_2\left(\frac{1}{x}\right),\; \text{Where } x = \frac{T}{m_\chi},\; g = 2 \text{ And } P_n(z) = 1 + \frac{(4n^2-1)}{8z}.$$

The Freeze-Out Procedure[10]

- For $\tau \ll \tau_{\rm F}$, $Y_\chi \simeq Y_\chi^{\rm eq}$ and so, BE can be Written as Follows: $\Delta' = -Y_\chi^{\rm eq\prime} - y\,\overline{\langle\sigma v\rangle}\Delta\left(\Delta + 2Y_\chi^{\rm eq}\right)\sqrt{g_b/g_q}$ With $\Delta = Y_\chi - Y_\chi^{\rm eq}$. The Freeze-Out Logarithmic Time $\tau_{\rm F}$ can be Defined by $\Delta(\tau_{\rm F}) = \delta_{\rm F} Y_\chi^{\rm eq}(\tau_{\rm F})$, where $\delta_{\rm F} \sim 1$ and Found by Solving Iteratively the Following Equation:

$$\left(\ln Y_\chi^{\rm eq}\right)'(\tau_{\rm F}) = -y_{\rm F}\overline{\langle\sigma v\rangle}\delta_{\rm F}(\delta_{\rm F}+2)Y_\chi^{\rm eq}(\tau_{\rm F})\sqrt{g_b}/\sqrt{g_q}(\delta_{\rm F}+1) \text{ with } y_{\rm F} = y(\tau_{\rm F}).$$

- For $\tau \gg \tau_{\rm F}$, $Y_\chi \gg Y_\chi^{\rm eq}$ and Therefore, BE can be Solved as Follows:

$$Y_{\chi 0} = \left(Y_{\chi\rm F}^{-1} + J_{\rm F}\right)^{-1},\; \text{Where } J_{\rm F} = \int_{\tau_{\rm F}}^{0} d\tau\,\sqrt{\frac{g_b}{g_q}}\,y\,\overline{\langle\sigma v\rangle} \text{ and } Y_{\chi\rm F} = (\delta_{\rm F}+1)\,Y_\chi^{\rm eq}(\tau_{\rm F}).$$

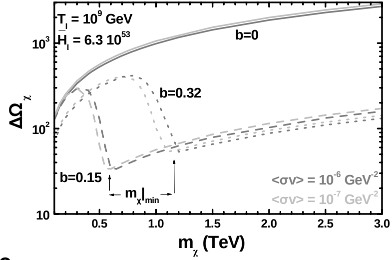
Our Final Result can be Derived As Follows: $\Omega_\chi = \rho_{\chi 0}/\rho_{\rm c0} = m_\chi s_0 Y_{\chi 0}/\rho_{\rm c0} \Rightarrow \boxed{\Omega_\chi h^2 = 2.748\cdot 10^8\; Y_{\chi 0}\; m_\chi/{\rm GeV}.}$

[10] *G. Jungman, M. Kamionkowski and K. Griest (1995); C.P (2005).*

CALCULATING $\Delta\Omega_\chi$

THE ENHANCEMENT OF $\Omega_\chi h^2$ W.R.T ITS VALUE IN THE SC, $\Omega_\chi h^2\big|_{\rm SC}$, CAN BE ESTIMATED, BY DEFINING $\boxed{\Delta\Omega_\chi = \frac{\Omega_\chi h^2 - \Omega_\chi h^2\big|_{\rm SC}}{\Omega_\chi h^2\big|_{\rm SC}}}$.

THE BEHAVIOR OF $\Delta\Omega_\chi$ AS A FUNCTION OF THE FREE PARAMETERS OF THE QKS CAN BE INFERRED FROM THE FIGURE ($a = 0.5$, $\bar{H}_{\rm I} = 6.3 \cdot 10^{53}$, $T_{\rm I} = 10^9$ GeV):



$\langle\sigma v\rangle$ (GeV^{-2})	10^{-7}	10^{-6}
$-\tau_{\rm F}$	$31.7 - 35.2$	$31.6 - 35.1$
	$b = 0.15$, $\tau_{\rm ext} \simeq -33.1$	
$\tau_{\rm F}^{\rm min}$	-33.3	-33.3
	$b = 0.32$, $\tau_{\rm ext} \simeq -33.8$	
$\tau_{\rm F}^{\rm min}$	-34.1	-34.0

COMMENTS

- FOR $b = 0$ WE OBTAIN A PURE KD ERA AND $\Delta\Omega_\chi$ INCREASES WHEN m_χ INCREASES OR $\langle\sigma v\rangle$ DECREASES.
- FOR $b \neq 0$, $\Delta\Omega_\chi$ DEPENDS CRUCIALLY ON THE HIERARCHY BETWEEN $\tau_{\rm F}$ AND $\tau_{\rm ext}$.
- AS m_χ INCREASES ABOVE 0.1 TeV, $-\tau_{\rm F}$ INCREASES AND MOVES CLOSER TO $\tau_{\rm ext}$ AND $\Delta\Omega_\chi$ DECREASES WITH ITS MINIMUM $\Delta\Omega_\chi\big|_{\rm min}$ OCCURRING AT $m_\chi = m_\chi\big|_{\rm min}$ WHICH CORRESPONDS TO $\tau_{\rm F}^{\rm min} \simeq \tau_{\rm ext}$.

Calculating $\Phi_{e^+}^{\chi\chi}$

The e^+ Flux Per Energy – in Units $\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ – at Earth from the χ Annihilation Can be Found From[11]:

$$\Phi_{e^+}^{\chi\chi}(E) = \frac{1}{2}\,\frac{v_{e^+}}{4\pi b(E)}\left(\frac{\rho_\odot}{m_\chi}\right)^2\langle\sigma v\rangle\int_E^{m_\chi} dE'\, I\left(\lambda_D(E,E')\right)\frac{dN_{e^+}}{dE'_{e^+}}\ ,\ \text{Where}$$

- $\frac{dN_{e^+}}{dE_{e^+}} = \begin{cases}\delta(E_{e^+}-m_\chi) & \text{for } \chi\chi \to e^+e^-,\\ (\frac{\alpha_{\rm em}}{\pi})A\exp[-(A_1y+A_1y^2)]+B_1+B_2y & \text{for } \chi\chi \to \mu^+\mu^-,\end{cases}$ Where[12] $J=F(m_\chi),\ J=A,A_1,A_2,B_1,B_2$.
- v_{e^+} is the Velocity of e^+, $y=E_{e^+}/m_\chi$, $\rho_\odot = 0.3\ \mathrm{GeV/cm^3}$ and $b(E)=E^2/(\mathrm{GeV}\,t_E)$ with $t_E=10^{16}$ s.
- $\lambda_D^2 = 4K_0t_E\left[\frac{(E'/\mathrm{GeV})^{\delta-1}-(E/\mathrm{GeV})^{\delta-1}}{\delta-1}\right]$ With $I(\lambda_D)=a_0+a_1\tanh\left(\frac{b_1-l}{c_1}\right)\left[a_2\exp\left(-\frac{(l-b_2)^2}{c_2}\right)+a_3\right]$ And $l=\log\left(\frac{\lambda_D}{\mathrm{kpc}}\right)$.

Basic Assumptions

As for the Prediction of any CDM Signal, There are Three Sources of Uncertainty:

- The CDM Distribution. We Adopt the Isothermal Halo Profile, to Avoid Troubles With Observations on γ-CRs[13].
- The Propagation of χ Annihilation Products. We Adopt the MED Propagation Model, Which Provides the Best Fits to the Combinations of the Various Data-sets[14]. It Fixes a's, b's and c's, K_0 and δ.
- The Astrophysical Backgrounds. We Adopt Commonly Assumed Background e^+ and e^- Fluxes Normalized With the Fermi-LAT Data.

[11] *E.A. Baltz and J. Edsjo (1999); J. Hisano et al. (2006); T. Delahaye et al. (2008); M. Cirelli, R. Franceschini and A. Strumia (2008).*
[12] *I.Z. Rothstein, T. Schwetz and J. Zupan (2009).*
[13] *G. Bertone, M. Cirelli, A. Strumia and M. Taoso (2009).*
[14] *K. Cheung, P.Y. Tseng and T.C. Yuan (2009).*

The χ^2 Analysis

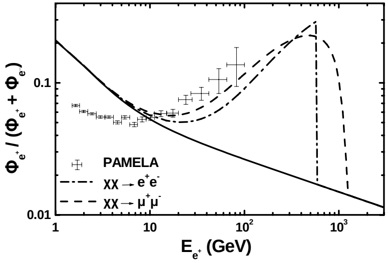
We Define the χ^2 Variables as Follows: $\chi^2_A = \sum_{i=1}^{N_A} \frac{\left(F^{\rm obs}_{Ai} - F^{\rm th}_{Ai}\right)^2}{\left(\Delta F^{\rm obs}_{Ai}\right)^2}$, with $F_A = \begin{cases} \Phi_{e^+}/\left(\Phi_{e^+}+\Phi_{e^-}\right) & \text{and } N_A = 7 \text{ for PAMELA,} \\ E^3_{e^+}\left(\Phi_{e^+}+\Phi_{e^-}\right) & \text{and } N_A = 26 \text{ for Fermi LAT,} \end{cases}$

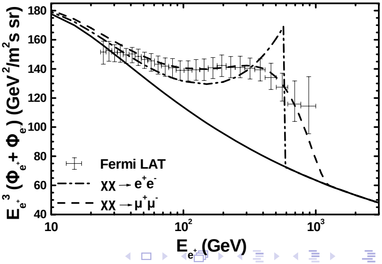
Where i Runs Over the Data Points of Each Experiment A, “obs” [“th”] Stands for Measured [Theoretically Predicted] Values.

The Best Fit Points

Performing a χ^2 Analysis We Find an Exceptionally Good Fit to PAMELA and Fermi-LAT Data for $\chi\chi \to \mu^+\mu^-$.

Annihilation Mode	$\chi^2\vert_{\rm min}$ / d.o.f	m_χ/ TeV	$\langle\sigma v\rangle$/ 10^{-7} GeV^{-2}	$\langle\sigma v\rangle_{\rm max}$/ 10^{-7} GeV^{-2}	$\Omega_\chi h^2\vert_{\rm SC}$ / 10^{-4}
$\chi\chi \to e^+e^-$	95/31	0.58	4.6	2.5	5.8
$\chi\chi \to \mu^+\mu^-$	24/31	1.28	19.5	16.5	1.4





The Preferred Regions From $e^{\pm}$-CR Anomalies

The Regions Which Are Favored at 95% [99%] c.l. by the Various Experimental Data on the $e^{\pm}$-CRs can Be Found Demanding

$$\chi^2 \lesssim \chi^2\big|_{\rm min} + 6\ \left[\chi^2 \lesssim \chi^2\big|_{\rm min} + 9.2\right]\ \text{with}\ \chi^2 = \begin{cases}\chi_1^2 & \text{for PAMELA,}\\ \chi_1^2 + \chi_2^2 & \text{for PAMELA and Fermi LAT,}\end{cases}$$

Where $\chi^2\big|_{\rm min}$ Can Be Extracted Numerically By Minimization of χ^2 w.r.t the Independent Parameters, m_{χ} and $\langle\sigma v\rangle$.

Observational Constraints

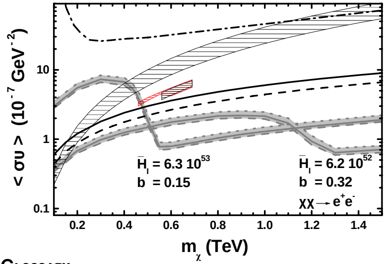
Large $\langle\sigma v\rangle$'s may Jeopardize the Predictions of BBN and Have an Impact on CMB Angular Spectra. Less Restrictive Constraints can be Also Imposed. Consistency with Observations Entails:

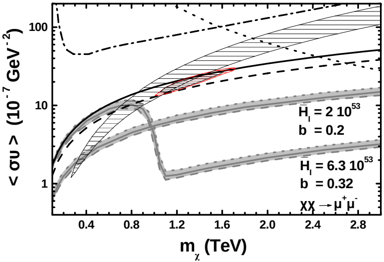
- The BBN Constraint[15]: $\langle\sigma v\rangle \leq 6\cdot 10^{-7}\ {\rm GeV}^{-2}\ \frac{2m_{\chi}}{E_{\rm vis}}\ \frac{m_{\chi}}{1\ {\rm TeV}}$ where $\frac{E_{\rm vis}}{m_{\chi}} = \begin{cases}2 & \text{for}\ \chi\chi \to e^+e^-,\\ 0.7 & \text{for}\ \chi\chi \to \mu^+\mu^-.\end{cases}$
- The CMB Constraint[16]: $\langle\sigma v\rangle \leq \frac{3.1\cdot 10^{-8}\ {\rm GeV}^{-2}}{f}\ \frac{m_{\chi}}{1\ {\rm TeV}}$ where $f \simeq \begin{cases}0.7 & \text{for}\ \chi\chi \to e^+e^-,\\ 0.24 & \text{for}\ \chi\chi \to \mu^+\mu^-.\end{cases}$
- Constraint from the γ-CRs[17]: $\langle\sigma v\rangle \lesssim \begin{cases}3\cdot 10^{-6}\ {\rm GeV}^{-2} & \text{for}\ \chi\chi \to e^+e^-,\\ 4\cdot 10^{-6}\ {\rm GeV}^{-2} & \text{for}\ \chi\chi \to \mu^+\mu^-.\end{cases}$ And the Isothermal Halo Profile.
- The Unitarity Constraint[18]: $\langle\sigma v\rangle \leq 8\pi\ {\rm GeV}^{-2}\ \left(\frac{m_{\chi}}{1\ {\rm GeV}}\right)^{-2}.$

[15] J. Hisano M. Kawasaki, K. Kohri, T. Moroi and K. Nakayama (2009).
[16] S. Galli, F. Iocco, G. Bertone and A. Melchiorri (2009); T.R. Slatyer, N. Padmanabhan and D.P. Finkbeiner (2009).
[17] G. Bertone, M. Cirelli, A. Strumia and M. Taoso (2009).
[18] K. Griest and M. Kamionkowski (1990); L. Hui (2001).

Putting Anything Together

Imposing All the Available Constraints we Can Delineate our Findings in the $m_\chi - \langle\sigma v\rangle$ Plane as Follows:





Glossary

Black Line	Upper Bound From	Region	Favored by
Solid	BBN	Sparse Black Hatched	PAMELA (95% c.l.)
Dashed	CMB	Dense Black Hatched	PAMELA and Fermi LAT (95% c.l.)
Dotted	Unitarity	Sparse Red Hatched	PAMELA and Fermi LAT (99% c.l.)
Dot-Dashed	γ-CRs	Light Gray Shaded	CDM Considerations

A Simultaneous Interpretation of the $e^{\pm}$-CR Anomalies Consistently with the Various Constraints can be Achieved in the Regions Where The Gray Shaded Areas Overlap The Lined Ones Below the Dashed Lines (We Take $a = 0.5,\ T_{\rm I} = 10^9$ GeV).

Final Score

We Considered the Explanation of the $e^{\pm}$-CR Anomalies Consistently with a Number of Observational Constraints. The Best-Fit $(m_\chi, \langle\sigma v\rangle)$'s Which Saturate the Most Stringent (CMB) Bound are Arranged in the Table:

	Fits to PAMELA And Fermi-LAT Data					
	$\chi\chi \to e^+e^-$			$\chi\chi \to \mu^+\mu^-$		
m_χ (TeV)	0.258			1.12		
$\langle\sigma v\rangle$ $\left(\text{GeV}^{-2}\right)$	$1.14 \cdot 10^{-7}$			$1.44 \cdot 10^{-6}$		
$\chi^2 - \chi^2\rvert_{\rm min}$	177			9		
$\Omega_\chi h^2\rvert_{\rm SC}$	0.0022			0.00019		
Combinations of Parameters Yielding $\Omega_\chi h^2 = 0.11$ In The QKS for $a = 0.5$ and $T_{\rm I} = 10^9$ GeV						
b	0	0.2	0.32	0	0.08	0.18
$\bar{H}_{\rm I}/10^{53}$	0.76	1.2	0.96	3.1	3.4	4.7
$T_{\rm KR}$ (GeV)	0.07	0.03	0.04	0.019	0.005	0.009

Final Remarks

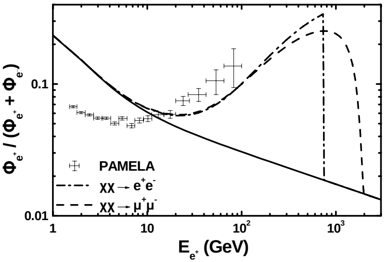
- The Regions Favored by PAMELA and Fermi LAT for $\chi\chi \to e^+e^-$ Can Be Excluded.
- Part of the Region Favored at 99% c.l. by PAMELA and Fermi LAT for $\chi\chi \to \mu^+\mu^-$ is Allowed. For the Best-Fit $(m_\chi, \langle\sigma v\rangle)$ we Obtain $\chi^2/\text{d.o.f} = 33/31$.
- The CDM Requirement can Be Satisfied by Adjusting the Parameters of the QKS. We Obtain $T_{\rm KR} < 0.07$ GeV.
- It Remains the Construction Of A Particle Model[19] With The Appropriate Couplings so that χ Annihilates into $\mu^+\mu^-$ With the Desired $\langle\sigma v\rangle$ Derived Self-Consistently With The (s)Particle Spectrum.

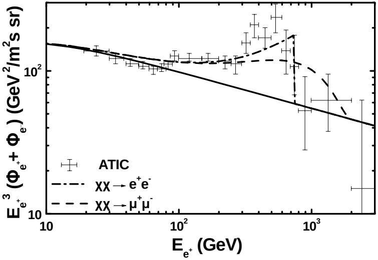
[19] *D. Feldman, Z. Liu and P. Nath (2009); R. Allahverdi et al. (2009); C. Balazs, N. Sahu and A. Mazumdar (2009)...*

Comparing with the Fitting to PAMELA and ATIC Data

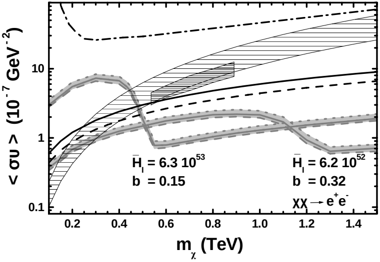
Performing a Similar χ^2 Analysis We Find that the Fit to PAMELA and ATIC Data is poorer for $\chi\chi \to \mu^+\mu^-$ than for $\chi\chi \to e^+e^-$ but the Required $\langle\sigma v\rangle$ is Closer to $\langle\sigma v\rangle_{\rm max}$. Also, $\chi^2\big|_{\rm min}$ /d.o.f of the Fit to PAMELA and Fermi-LAT Data is Lower than the one of the Fit to PAMELA and ATIC Data.

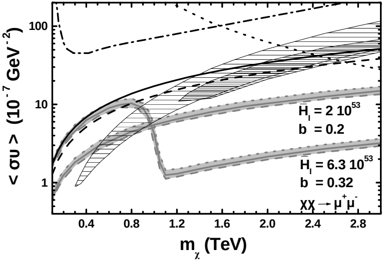
Annihilation Mode	$\chi^2\big\|_{\rm min}$ / d.o.f	m_χ/ TeV	$\langle\sigma v\rangle$/ 10^{-7} GeV^{-2}	$\langle\sigma v\rangle_{\rm max}$/ 10^{-7} GeV^{-2}	$\Omega_\chi h^2\big\|_{\rm SC}$ / 10^{-4}
$\chi\chi \to e^+e^-$	67/26	0.74	7.14	3.3	3.8
$\chi\chi \to \mu^+\mu^-$	76/26	2	28.6	26	0.97





Constraints in the $m_\chi - \langle\sigma v\rangle$ Plane





	Fits to PAMELA And ATIC Data				
	$\chi\chi \to e^+e^-$			$\chi\chi \to \mu^+\mu^-$	
m_χ (TeV)	0.47			2	
$\langle\sigma v\rangle$ $\left(\mathrm{GeV}^{-2}\right)$	$2.1 \cdot 10^{-7}$			$2.6 \cdot 10^{-6}$	
$\chi^2 - \chi^2\|_{\rm min}$	15.8			1	
$\Omega_\chi h^2\|_{\rm SC}$	0.0012			0.0001	
Combinations of Parameters Yielding $\Omega_\chi h^2 = 0.11$ In The QKS for $a = 0.5$ and $T_{\rm I} = 10^9$ GeV					
b	0	0.2	0.32	0	0.08
$\bar{H}_{\rm I}/10^{53}$	0.88	1.35	1	3.5	3.7
$T_{\rm KR}$ (GeV)	0.06	0.03	0.097	0.017	0.005