Title: AMS02 results support the secondary origin of cosmic ray positrons

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Abstract: We show that the recent AMS02 positron fraction measurement is perfectly consistent with a secondary origin for positrons, and does not require additional primary sources such as pulsars or dark matter. Within the secondary model the AMS02 data imply a cosmic ray propagation time in the Galaxy of about one Myr and an average traversed interstellar matter density of about 1/cc at a rigidity of 300 GV. These results may hint that high energy cosmic rays are confined to a thin halo of scale height similar to the gaseous disk.
AMS02 results support the secondary origin of cosmic ray positrons

Kfir Blum, IAS

With: Boaz Katz (IAS), Eli Waxman (Weizmann)
1305.probably-next-week

Katz, KB, Waxman; MNRAS 405 (2010) 1458
KB; JCAP 1111 (2011) 037

PI 05/03/2013
What we’re talking about:

A new measurement of antimatter in space. *Want to find dark matter*

- positrons: curious increase with energy!

What can we really learn?

AMS02: on board ISS since May 2011

[Link](https://cdsweb.cern.ch/record/1537419)
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A few years back: PAMELA (2009)

First reliable measurement of antimatter density in space, E~100 GeV

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Letter
Nature 458, 607-609 (2 April 2009) | doi:10.1038/nature07942; Received 28
February 2009
An anomalous positron abundance in cosmic
rays with energies 1.5–100 GeV
PAMELA (2009)

Despite many claims in literature: consistent with all known constraints.
But intriguing rise with energy

upper bound for “standard” mechanism

Katz, KB, Waxman; MNRAS 405 (2010) 1458
Typical dark matter / Pulsar model:
AMS02 (2013)

Big experimental step.
AMS02 (2013)

Big experimental step.
AMS02 (2013)

Big experimental step.
Pulsars continue to exist, and plausibly also dark matter
Pulsars continue to exist, and plausibly also dark matter
Galactic CRs

- CRs fill our Galaxy. Galactic: up to few PeV, at least. Energy density \( \sim \text{eV/cm}^3 \)
- **Primaries**: p, C, Fe, … stellar material, accelerated to high energy
- **Secondaries**: B, Be, Sc, Ti, V, … fragmentation of primaries on ISM

Antimatter occurs as secondary

\[
pp \rightarrow pn\pi^+ \rightarrow ppe^-e^+\nu_e\bar{\nu}_e\nu_\mu\bar{\nu}_\mu
\]

primary “beam” \hspace{1cm} ambient interstellar gas \hspace{1cm} secondary products

“target”

high energy particles
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- **Unknown:**
  propagation (what determines distribution)
  primary source (what put the CRs there in the first place?)

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Gaensler et al
Nature 478 (2011) 214-217
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[Image of a plot showing the distribution of CRs with annotations.]
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Nature 478 (2011) 214-217
A simple analysis of stable secondaries

• High-energy flux follows *empirical* relation:  
  \[ J_S = \frac{c}{4\pi} X_{esc} \tilde{Q}_S. \]
  
  \[ (S = ^9\text{Be}, \text{ B, Sc, } \bar{p}, \ldots) \]

• \( \tilde{Q}_S \) = Local net production per unit column density of ISM
• \( X_{esc} \) = CR *grammage* = mean column density. \( X_{esc} \) *no species label, S* 

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![Graphs showing flux ratios vs. energy (GeV/n) for B/C and (Sc-Cr)/Fe](image-url)
A simple analysis of stable secondaries

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**Graphs:**

- **B / C**
  - Engelmann et al (1990)
  - Flux Ratio vs. Energy (GeV/n)

- **(Sc-Cr) / Fe**
  - Flux Ratio vs. Energy (GeV/n)

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*Pirsa: 13050015 Page 24/60*
A simple analysis of stable secondaries

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**Graphs:**

1. **B / C**
   - **Engelmann et al. (1990)**
   - **DATA**:
     - HEAD-3 C2
     - Gupta and Webber - (1988)
     - Dwyer and Meyer - (1987)

2. **(Sc-Cr) / Fe**
   - **DATA**:
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![Graphs showing flux ratio vs. energy](image1)

![Graphs showing flux ratio vs. energy](image2)
A simple analysis of stable secondaries

- High-energy flux follows \textit{empirical} relation:
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**Graphs:**

- **B / C**
  - Engelmann et al (1990)
  - FLUX RATIO
  - ENERGY (GeV/n)

- **(Sc-Cr) / Fe**
  - FLUX RATIO
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A simple analysis of stable secondaries

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  \[ J_S = \frac{c}{4\pi} \ X_{esc} \ \tilde{Q}_S \]
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![Graphs showing flux ratios vs. energy](image-url)
A simple analysis of stable secondaries

- High-energy flux follows empirical relation: \[ J_S = \frac{c}{4\pi} X_{esc} \tilde{Q}_S \]
  \[ (S = ^9\text{Be}, \ B, \ Sc, \ p, \ ...) \]

- \( \tilde{Q}_S \) = Local net production per unit column density of ISM
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![Graph 1](Engelmann et al. (1990))

![Graph 2](HEAO-3 C2, Gupta and Webber (1988), Dwyer and Meyer (1987))
A simple analysis of stable secondaries

- High-energy flux follows simple relation

\[ J_e = \frac{n}{E} \gamma_{\text{me}} Q \]

- \( n = \frac{N_{\text{tot}}}{A_{\text{obs}}} \)
- \( \gamma_{\text{me}} = \text{CR: grammage} \)
- \( N_{\text{tot}} = \text{mean column density} \)
- \( A_{\text{obs}} = \text{no special label} \)

\[ E \]
A simple analysis of stable secondaries

- High-energy flux follows empirical relation:

$$J_e = \frac{1}{16} \gamma \alpha Q_e$$

- $\gamma$ = Lorentz factor
- $\alpha$ = energy index
- $Q_e$ = energy flux

- $\chi_{\text{ISM}}$ = Column density per unit column density of ISM
- $\chi_{\text{C}^+}$ = Column density of C$^+$
- $\chi_{\text{H}}$ = Column density of H
- $\chi_{\text{H}_2}$ = Column density of H$_2$
Example: antiprotons

\[
\frac{J_{\bar{p}}}{J_p} = 10^{-\gamma + 1} \xi_{\bar{p},A>1} C_{\bar{p},pp}(\varepsilon) \frac{\sigma_{pp, inel,0}}{m_p} X_{esc} \frac{1}{1 + \frac{\sigma_{\bar{p}}}{m_p} X_{esc}}
\]
Example: antiprotons

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\]
Antiprotons

Obviously consistent with secondary.
Beside from that, **no lesson** for details of propagation

Merely this:

\[
\frac{n\bar{p}}{n_{\text{Boron}}} = \frac{Q\bar{p}}{Q_{\text{Boron}}}
\]
Diffusion models fit grammage

Maurin, Donato, Taillet, Salati
Diffusion models fit grammage

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Diffusion models fit grammage

\[ X_{\text{esc}} = X_{\text{disc}} \frac{L c}{2D} 2R \sum_{k=1}^{\infty} J_0 \left[ v_k \left( r_s / R \right) \right] \frac{\tanh \left[ v_k (L / R) \right]}{v_k^2 J_1(v_k)} \]
Positrons

\[ \frac{J_{e^+}}{J_p} = f_{s,e^+} 10^{-\gamma+1} \xi_{e^+,A>1} C_{e^+,pp}(\varepsilon) \frac{\sigma_{pp,inel,0}}{m_p} X_{esc} \]

\[ pp \rightarrow pn\pi^+ \rightarrow ppe^-e^+\nu_e\bar{\nu}_e\nu_\mu\bar{\nu}_\mu \]

<table>
<thead>
<tr>
<th>h</th>
<th>Exclusive reaction</th>
<th>( \bar{M}_X ) (GeV ( c^{-2} ))</th>
<th>( \sqrt{\bar{s}} ) (GeV)</th>
<th>( E_1 ) (GeV)</th>
<th>( T_1 ) (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi^- )</td>
<td>( pn\pi^- )</td>
<td>1.878</td>
<td>2.018</td>
<td>1.233</td>
<td>0.295</td>
</tr>
<tr>
<td>( \pi^- )</td>
<td>( pp\pi^- )</td>
<td>2.016</td>
<td>2.156</td>
<td>1.540</td>
<td>0.602</td>
</tr>
<tr>
<td>( \pi^0 )</td>
<td>( pp\pi^0 )</td>
<td>1.876</td>
<td>2.011</td>
<td>1.218</td>
<td>0.280</td>
</tr>
<tr>
<td>( \kappa^- )</td>
<td>( \Lambda^0 p\kappa^- )</td>
<td>2.053</td>
<td>2.547</td>
<td>2.520</td>
<td>1.582</td>
</tr>
<tr>
<td>( \kappa^- )</td>
<td>( pp\kappa^- )</td>
<td>2.370</td>
<td>2.864</td>
<td>3.434</td>
<td>2.496</td>
</tr>
<tr>
<td>( \bar{p} )</td>
<td>( ppp\bar{p} )</td>
<td>2.814</td>
<td>3.752</td>
<td>6.566</td>
<td>5.628</td>
</tr>
<tr>
<td>( p )</td>
<td>( pp )</td>
<td>0.938</td>
<td>1.876</td>
<td>0.938</td>
<td>0</td>
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Positron anomaly?

Claims of a primary source:

- The electrons are assumed to have the same production spectrum as the protons, and to suffer the same energy losses as the positrons $f_{e,-} = f_{e,+}$.

- The $e^+$ flux, including the energy loss suppression, is calculated within a specific propagation model.
Positron anomaly?

Claims of a primary source:

- The electrons are assumed to have the same production spectrum as the protons, and to suffer the same energy losses as the positrons $f_{s,e^-} = f_{s,e^+}$.

- $e^+$ flux, including the energy loss suppression, is calculated within a specific propagation model.
The case for a secondary source:

To be clear: positron flux suppression, that decreases with increasing energy, is interesting, not naively expected, and worthy of exploring (among other CR puzzles).

But:

- Over all scale alright throughout measured range, with no free parameters
- Broad consistency with antiprotons
- No known contradiction with any other experimental data
- Non-trivial prediction from 2009 confirmed
Propagation time scales: radioactive nuclei

B/C teach us the mean column density of target material traversed by CRs

Does not tell the time it takes to accumulate this column density

A beam of carbon nuclei traversing \(1\text{g/cm}^2\) of ISM produces the same amount of boron, whether it spent 1kyr in a dense molecular cloud, or 1Myr in rarified ISM

→ Radioactive nuclei carry time info (as do positrons)
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➔ Radioactive nuclei carry time info (as do positrons)
Comparing with radioactive nuclei

Time scales:
cooling vs decay

(Ignoring K-N)
Comparing with radioactive nuclei

Time scales:
cooling vs decay
Comparing with radioactive nuclei

\[ f_{s,10\text{Be}} \approx 0.4 \]
\[ f_{s,e^+} \approx 0.3 \]
Radioactive nuclei: constraints on $t_{\text{esc}}$

- Rigidity dependence: hints from current data
- Cannot (yet) exclude rapidly decreasing escape time
- AMS-02 should do better!

Need to tell between these fits.

KB; JCAP 1111 (2011) 037
Summary: AMS02 results support secondary origin for e+

Consistent with simplest reliable calculation,

No need for dark matter annihilation / Pulsar contribution

Interesting cosmic ray physics
Cosmic ray escape time falling faster than column density?
Escape time < Myr at E~300 GeV?

Upcoming tests with AMS02
Robust determination of B/C at high energy
– calibrate out propagation
Relativistic elemental ratios  Be/B, Cl/Ar, Al/Mg

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Escape time $< \text{Myr}$ at $E \sim 300$ GeV?

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