SNRs as a simple explanation for PAMELA/ATIC anomalies

or

“Anomalous” positrons from very normal sources

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SNR are the canonical sources of CRs

- Mechanism exists ($1^{st}$ order diffusive / shock acceleration)
- Ginzburg & Syrovatskii (1963) - Energy requirements agree with CR density/lifetime (assuming ~ 3% - 10% efficiency)
- Observations of Synchrotron from SNe reveals efficient electron acceleration
Once formed, they diffuse
• Electrons and Protons are mostly accelerated by supernova/interstellar medium (ISM) shocks.

• Pairs are produced by the protons interacting with the ISM

• Positron / Electron ratio should decrease with energy!
PAMELA
PAMELA’s anomaly:
Decay of exotic particles (WIMPs)
Astrophysical Sources of Pairs: Pulsars
These solutions require

NEW PHYSICS

or

NEW ASTROPHYSICS

or proton contamination?

Okam’s razor: Is there a simpler solution?
Consider a Local Source

• If CRs primarily come from a local source, it takes them time!

• Along the way, electrons cool though Synchrotron & Compton (on CMB, IR background and starlight).

\[ \frac{dE}{dt} = -bE^2 \]

\[ b = \frac{4\sigma c}{3(mc^2)^2} \left( \frac{B^2}{8\pi} + w_{ph} \right) \]

• Above some energy, they don’t have enough time to reach us.
\[ D = D_0 \left( \frac{E}{E_0} \right)^{1/3} \]

\[ t_{\text{diff}} \approx \frac{r^2}{2D_0} \left( \frac{E}{E_0} \right)^{-1/3} \]

\[ t_{\text{cool}} \approx \frac{1}{bE} \equiv \tau_c \frac{E_0}{E} \]

\[ t_{\text{cool}}(E_b) \approx t_{\text{diff}}(E_b) \]

\[ E_b \approx \left( \frac{2D_0 E_0^{1/3}}{r^2 b} \right)^{3/2} \approx \left( \frac{\tau_c}{a} \right)^{3/2} E_0 \]

\[ \approx \left( \frac{172 \text{ Myr}}{24 \text{ Myr}} \right)^{3/2} 1 \text{ GeV} \approx 20 \text{ GeV} \]
This means that...

- Above $E_b \sim 20$ GeV, the electrons will start cooling.
- Positrons however, form along the way from proton-ISM interactions.
- Therefore the positron/electron ratio will increase
• Primary electron cool and disappear before reaching earth
• Secondary electron/positron form nearer and can reach earth before cooling
- Electrons from Spiral arms above ~ 20 GeV cool (synchrotron and inverse-Compton) before reaching the solar system!
- Protons do not cool, so positron production near us does not care (too much) about cooling.
The graph illustrates the comparison between the spectra of protons ($p$) and electrons ($e^-$) in the galaxy. The $e^-$ spectrum shows a faster diffusion out of the galaxy compared to the $p$ spectrum at the source. The $p$ spectrum in the galaxy is also shown, indicating a different behavior compared to the $e^-$ spectrum.
Technical Complications

- Adding the effect of escape from the galaxy at a vertical height of \( \sim 1 \text{kpc} \)

\[
\Phi_e^-(x) \propto \exp \left[ -2\sqrt{\frac{\tau_x}{\tau_e} + \frac{\tau_x}{\tau_c}} \right] \frac{D}{\sqrt{1 + \tau_e/\tau_c}}
\]

- And the production of positron/electrons by protons

\[
\Phi_e^+(x) \propto \frac{\tau_c}{D} \left( \exp \left[ -\sqrt{\frac{2\tau_x}{\tau_e}} \right] - \frac{1}{\sqrt{1 + \tau_e/\tau_c}} \exp \left[ -\sqrt{\frac{2\tau_x}{\tau_c} + \frac{2\tau_x}{\tau_e}} \right] \right).
\]
But what is the source?

- SNRs in the spiral arm
Most SNe occur in the spiral arms

- In the Milky Way: Almost all SNe are non-Type Ia, and occur where almost all star formation takes place: In the Spiral Arms

- Meteorites: Show that density changes by a factor of > 2.5

- Deconvolved Synchrotron: Shows arm to inter-arm ratio of ~ 3
Why Primarily Spiral Arms?
SNR Distribution in NGC 6946

6946 is similar in shape to that of M33, although the SNRs in NGC 6946 are consistently more luminous than those in M33. This may well be because of the greater mass and higher star formation rate in NGC 6946, leading to a greater steady state population of SNRs. The luminosity functions of both NGC 6946 and M33 have abrupt cutoffs at lower flux densities because of the surface brightness limits of the respective radio surveys.

4. PROGENITOR STARS OF THE RADIO-SELECTED SNRS

In order to investigate which type of SNe is responsible for radio-selected SNRs, and therefore the CR electron acceleration, we have plotted the positions of the radio-selected SNRs on an Hα image of similar resolution and compared the nonthermal radio emission with the Hα emission. Figure 2 illustrates the positions of the radio-selected SNRs relative to the Hα arms in NGC 6946. The spiral arms were defined in Matonick & Fesen (1997), in which they used an optical continuum image of NGC 6946 that best showed the spiral arm structure and traced the spiral arms along the peak surface brightness contours of each arm (see Fig. 3). We used the same width of the spiral arms, 25°, that Matonick & Fesen (1997) used in order to compare directly our statistical properties with their criteria.

A random population of 40 sources was selected to compare with the optical and radio-selected SNRs. The random sources were generated in the same region in the galaxy as the radio-selected SNRs, at a distance from the galaxy center of roughly 10 kpc. A total of 10 sources were selected in the central core, 15 sources on the outer edges of the galaxy, and 15 sources on the interarm regions of the galaxy. The radio SNRs were separated into three categories: those on the central axis of a spiral arm, those on the edge of a spiral arm, and those in the interarm regions of the galaxy.
Monte Carlo Model

CR escape

2l_H

Periodic

Disk SNRs

Nearby SNRs

Spiral Arm SNRs

Sun

CR Diffusion: D~E^β
The Resulting $\frac{e^+}{(e^+ + e^-)}$ ratio
$e^+/(e^++e^-)$ ratio and $e^-$ spectrum
What about ATIC?

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance [kpc]</th>
<th>Age [yr]</th>
<th>˙E [ergs/s]</th>
<th>E_{out}^{ST} [GeV]</th>
<th>E_{out}^{CCY} [GeV]</th>
<th>f ±</th>
<th>Contribution from nearby KNOWN young SNRs: Geminga, Monogem, Gela LoopI and Cygnus Loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geminga [J0633+1746]</td>
<td>0.16</td>
<td>3.42 × 10^5</td>
<td>3.2 × 10^{34}</td>
<td>0.360</td>
<td>0.344</td>
<td>0.013</td>
<td>0.053 0.005 0.70</td>
</tr>
<tr>
<td>Monogem [B0656+14]</td>
<td>0.29</td>
<td>1.11 × 10^5</td>
<td>3.8 × 10^{33}</td>
<td>0.084</td>
<td>0.456</td>
<td>0.004</td>
<td>0.372 0.015 0.14</td>
</tr>
<tr>
<td>Vela B[0833-45]</td>
<td>0.29</td>
<td>1.11 × 10^5</td>
<td>0.9 × 10^{34}</td>
<td>0.044</td>
<td>0.133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loop I [SNR]</td>
<td>1.30</td>
<td>5.64 × 10^4</td>
<td>4.5 × 10^{34}</td>
<td>1.060</td>
<td>0.677</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cygnus Loop [SNR]</td>
<td>0.44</td>
<td>2 × 10^4</td>
<td>0.3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\[ \phi_+ + \phi_- \text{ [GeV}^2 \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}] = 2, \text{ MED diffusion setup, ST model} \]

\[ \text{Loop I} \]

\[ \text{Geminga} \]
Conclusions

- Taking the real distribution of SNRs gives the correct positron/electron energy behavior.

- No free parameters give the correct break energy.

- Nearby young known SNRs explain ATIC

- Predictions:
  - $\frac{e^+/e_{\text{tot}}}{e_{\text{tot}}}$ ratio should saturate < 50%
  - At higher energies the ratio should decrease! (due to fresh electrons)
The End ?
Results