Indirect DMA in the light of INTEGRAL
HEAT, EGRET and WMAP Haze

• 511 keV emission from the galactic bulge

• The HEAT positron excess

• EGRET’s galactic gamma ray spectrum

• EGRET’s extragalactic gamma ray spectrum

• The WMAP haze

Dan Hooper – SUSY07
Indirect Searches For Particle Dark Matter
Direct evidence for convective winds in Milky Way from X-rays (ROSAT)


“Earlier models had shown that a steady state wind driven by cosmic rays pervading the entire Milky Way could blow away about a solar-mass-worth of gas per year. Everett et al. find a similar gas loss of 2.1 solar masses per year from the best fit to their X-ray data. In their picture, the cosmic-ray pressure is crucial to the existence of a large-scale wind in the Milky Way.”

NGC 253

Our parametrization from fitting all CR data with modified GALPROP

Fit to ROSAT data, Everett et al. arXiv:0710.3712v1
Three independent measurements explained by convection dominated propagation

1. ROSAT X-Ray maps of hot gas in halo

2. Integral absence of positron annihilation in disk

3. Small gradient in EGRET diffuse gamma rays

Conventional diffusion model

Properties:
- CR diffuse in leaky box
- Secondaries $\propto$
- CR density $\times$ gas density
- CR Lifetime given by size of box

DMA in diffusion dominated model:
- charged particles strongly enhanced compared with gamma rays, since gammas escape and charged particles rattle around for $10^7$ yrs.

Enhancement factor:
- $N_{pb}/N_{\gamma} \approx O(1)$ instead of expected $O(10^{-3})$
- So DMA does not produce many antiprotons/positrons, but average density becomes large in a “storage tank”

In convection dominated models most charged particles in halo are “blown by the wind”.

Wim de Boer, Karlsruhe
PPC08, Albuquerque, May. 21, 2008
Convection dominates for low energies

Diffusion coeff:
\[ D_R(R,Z) = D_{R0} E^{0.33} \]
\[ D_Z(R,Z) = D_{Z0} E^{0.33} \]

Our parametrization from fitting all CR data with modified GALPROF:

\[ V(R,Z) = V_0 + \frac{V_d}{dZ} \]
\[ V(R) \propto \text{Galactic Wind} \]
\[ \propto \text{SNR}(R) \]

Consequence of large convection dominated region -> observed CR spectra are LOCAL spectra. Lifetime and flux of secondaries determined by LOCAL gas density and propagation in R, not in Z.
Energy loss time of protons \( \gg \) diffusion time, so spectrum same everywhere. NOT for electrons.

Same proton spectrum everywhere allows reliable calculation of shape of GeV gamma ray spectrum. Intensity fitted by free normalization.
Proton density distributions

DIFFUSION DOM.

CONVECTION DOM.
Electron density distributions

DIFFUSION DOM.

CONVECTION DOM.

Wim de Boer, Karlsruhe
PPCO8, Albuquerque, May. 21, 2008
Indirect DMA in the light of INTEGRAL HEAT, EGRET and WMAP Haze

- 511 keV emission from the galactic bulge

- The HEAT positron excess

- EGRET’s galactic gamma ray spectrum

- EGRET’s extragalactic gamma ray spectrum

- The WMAP haze

Dan Hooper – SUSY07
Indirect Searches For Particle Dark Matter
INTEGRAL 511 keV positron annihilation signal

Observation: strong annihilation from bulge, little from disk

$^{26}\text{Al}$ both from disk and bulge. Both from SN explosions.

Question: where did positrons from disk disappear?
Why Bulge/Disk ratio so large?

Expect: $B/D=O(10^{-1})$, observed $B/D=O(\text{a few})$!!

Solution: a) additional source in bulge. DMA? Hooper et al.

Need unnatural WIMP mass of few MeV 😞

b) convection dominating for low energy positrons
so they are blown to halo by Galactic winds and find no e-
Positron production in SN1a

Major radioactivity in SN: $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

- Core collapse SN (Massive stars): $M_{\text{Ni56}} \sim 0.07 M$  
- $M_{\text{Envelope}} \sim 10 M$

- Thermonuclear SN (White dwarfs): $M_{\text{Ni56}} \sim 0.7 M$  
- $M_{\text{Envelope}} \sim 0.7 M$

Thermonuclear SN (SN1a): release more $e^+$ which escape easier (in principle) from the expanding envelope than in the case of SN1

Number of positrons produced per SN1a:

$$N = 0.19 M_{\text{Ni56}} M N_A / 56 \sim 3 \times 10^{54}$$

Frequency of SN1a in MW:

$$f \sim 0.5 / 100 \text{ yr} \sim 1.6 \times 10^{-10} \text{ s}^{-1}$$

Rate of positrons released by MW SN1a:

$$R = f N \sim 4.5 \times 10^{44} \text{ s}^{-1}$$

OK if just 3% of them annihilate in the ISM!
Surprisingly:

SN1a emit most positrons in the halo, NOT in the disk

With isotropic diffusion they would return to disk and annihilate.

With anisotropic diffusion they escape to outer halo.

In the bulge they still find electrons to annihilate, so a large B/D is expected!

JUST BECAUSE OF the different GEOMETRY of bulge and disk.
NO annihilation inside MC, as predicted by Chandran model (Jean, Knoedlseder, Gillard, Guessoum, Ferriere..)

NO annihilation in molecular clouds (MC), although 75% of mass in MC. Why? Either volume of MC too small OR MC are magnetic mirrors as postulated by Chandran!

Parameters | Measured values
--- | ---
$f_m$ (Molecular) | 0.00 \(\pm 0.08\) \(\pm 0.02\)
$f_c$ (Cold) | 0.00 \(\pm 0.23\) \(\pm 0.04\)
$f_{wn}$ (Warm Neutral) | 0.49 \(\pm 0.02\) \(\pm 0.02\)
$f_{wi}$ (Warm Ionized) | 0.51 \(\pm 0.03\) \(\pm 0.02\)
$f_h$ (Hot) | 0.00 \(\pm 0.005\) \(\pm 0.00\)
$x_{gr}$ (Grain fraction) | 0.00 \(\pm 1.20\) \(\pm 0.20\)

\(\langle n \rangle_{\text{cm}^{-3}}\) | 1.58 | 0.26 | 0.26 | 0.08 | 8.9 \(\times 10^{-3}\)
\(n_{\text{cm}^{-3}}\) | 3600 | 146 | 1.46 | 0.77 | 0.012
\(\Phi\) | 0.0004 | 0.002 | 0.18 | 0.10 | 0.72
\(d_{max}\) (pc) | 1.0 | 4.8 | 47.9 | 44.0 | 5.6 \(\times 10^3\)
Are Molecular Clouds magnetic mirrors? (known to have strong frozen magnetic fluxes)

CONFINEMENT AND ISOTROPIZATION OF GALACTIC COSMIC RAYS BY MOLECULAR-CLOUD MAGNETIC MIRRORS WHEN TURBULENT SCATTERING IS WEAK

Benjamin D. G. Chandran
Department of Physics and Astronomy, University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242; benjamin-chandran@uiowa.edu
Received 1998 June 25; accepted 1999 August 6

It is shown that Galactic cosmic rays can be effectively confined through magnetic reflection by molecular clouds. Scattering from traps isotropizes CR fluxes!

Integral excess of positrons in bulge because positrons are trapped in magnetic mirrors between gas clouds? In disk positrons are ejected OUTSIDE disk and escape into halo!
The van Allen belts are trapped cosmic rays in magnetic mirrors of earth.

Radiation in inner belt: 25 Sv/yr inside space ship
Lethal dose for human: 3 Sv/h
Satellites switch off electronics, when entering dense radiation areas.
Two more parameters compared with isotropic diffusion: $D_{RR}/D_{ZZ}$ and "<grammage>" for more scattering by trapping

Table 1: Parameters of anisotropic propagation model with trapping

<table>
<thead>
<tr>
<th>name</th>
<th>implementation</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection spectra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protons/nuclei</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrons</td>
<td>$q_p = (\frac{\rho}{\rho_0})^\alpha$</td>
<td>$\rho_0 = 4 \cdot 10^3 MV$, $\alpha = 2.19$</td>
</tr>
<tr>
<td></td>
<td>$q_e = (\frac{E}{\rho_0})^\alpha$</td>
<td>$\rho_0 = 4 \cdot 10^3 MV$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 0.5$ for $\rho &lt; 1 \cdot 10^3 MV$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 2.0$ for $1 \cdot 10^3 MV &lt; \rho &lt; 4 \cdot 10^3 MV$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 2.6$ for $4 \cdot 10^4 MV &lt; \rho$</td>
</tr>
<tr>
<td>Transport parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffusion coefficient</td>
<td></td>
<td>disk</td>
</tr>
<tr>
<td>Diffusion coefficient \ perpendicular disk</td>
<td>$D_{zz} = D_{zz0}(\frac{\rho}{\rho_0})^\delta \cdot f_2(R, z)$</td>
<td>$D_{zz0} = 5.5 \cdot 10^{29} \text{ cm}^2 \text{ s}^{-1}$, $\rho_0 = 4 \cdot 10^3 MV$, $\delta = 0.33$</td>
</tr>
<tr>
<td>Convection speed</td>
<td>$V(R, z) = f(r)(V_0 \cdot \Theta(</td>
<td>z</td>
</tr>
<tr>
<td>Alvfen speed</td>
<td>$v_\alpha$</td>
<td>$v_\alpha = 50 \frac{\text{km}}{\text{s}}$</td>
</tr>
<tr>
<td>&quot;grammage parameter&quot;</td>
<td>$g$</td>
<td>12</td>
</tr>
</tbody>
</table>
Secondary production (B/C) and cosmic clocks ($^{10}\text{Be}/^9\text{Be}$)

- $^{10}\text{Be}$ ($t_{1/2} = 1.51$ Myr) is cosmic clock: lifetime of cosmics $10^7$ yrs.
- $^{10}\text{Be}/^9\text{Be}$ determines escape time
- $\text{B/C} = \text{secondary/prim. determines grammage}$ (smaller than disc!)
  - In GALPROP: by large halo
  - In CHANDRAN: by reflecting molecular clouds or slow diffusion

In GALPROP: by large halo
In CHANDRAN: by long trapping.
Basic principle for indirect dark matter searches

From rotation curve:

- Forces: \( \frac{mv^2}{r} = GmM/r^2 \)
- So \( M/r = \text{const.} \) for \( v = \text{cons.} \)
- \( \rho \propto (M/r)/r^2 \), so \( \rho \propto 1/r^2 \) for flat rotation curve

Divergent for \( r = 0 \)?
- Cuspy, cored?
- New N-body simulations:
  - Diffuse component cuspy
  - Clumpy component cored, see Springel, Frenk, et al.
  - arXiv:0801.1127v1
  - “Einasto profile”

If flux and shape measured in one direction, then flux and shape fixed in all (=180) sky directions!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

THIS IS AN INCREDIBLE CONSTRAINT, LIKE SAYING I VERIFY THE EXCESS AND WIMP MASS WITH 180 INDEPENDENT MEAS.
Background + signal describe EGRET data!

Fitted known shapes of background and DMA (from accelerator experiments) with free normalizations. W. de Boer et al., A&A (2005)
Analysis of EGRET Data in 6 sky directions

- A: inner Galaxy ($l = \pm 30^\circ, |b| < 5^\circ$)
- B: Galactic plane avoiding A
- C: Outer Galaxy
- D: low latitude (10-20°)
- E: intermediate lat. (20-60°)
- F: Galactic poles (60-90°)

Total $\chi^2$ for all regions = 28/36 $\Rightarrow$ Prob. = 0.8 Excess above background $> 10\sigma$. 
Halo density on scale of 300 kpc
(from normalization factors in 180 sky directions)

Cored isothermal profile with scale 4 kpc
Total mass: $O(10^{12})$ solar masses
Halo density on scale of 30 kpc

Enhancement of inner (outer) ring over $1/r^2$ profile 6 (8).
Mass in rings 0.3 (3)% of total DM
The Milky Way and its 13 satellite galaxies

Tidal force $\propto \Delta F_G \propto 1/r^3$
Tidal streams of dark matter from CM and Sgt

From David Law, Caltech
N-body simulation from Canis-Major dwarf galaxy

A comprehensive model for the Monoceros tidal stream


Wim de Boer, Karlsruhe  PPC08, Albuquerque, May. 21, 2008
Gas flaring in the Milky Way


Gas flaring needs EGRET ring with mass of $2 \times 10^{10} M_\odot$!
EGRET Excess predicts shape of rotation curve!

- **Rotation Curve**
  - R0 = 8.3 kpc
  - R0 = 7.0 kpc

Note: Absolute value of rotation curve depends on distances. But chance of slope can ONLY be explained by ringlike structure.

Normalize to solar velocity of 220 km/s
The dark connection between Canis Major, Monoceros Stream, gas flaring, the rotation curve and the EGRET excess

From EGRET excess of diffuse Galactic gamma rays
- Determination of WIMP mass
- Determination of WIMP halo
  (= standard halo + DM rings)

Confirmation:
- Rotation curve
- Canis Major/Monoceros stream
- Gas flaring

Objections
- EGRET data wrongly calibrated?
- Antiproton flux too high?
- Integral 511 keV a better cand?
- Surface density too high?
- WMAP haze different profile?
- Extraterr. Gamma rays inconsist?
- Xenon10 excludes Egret interpr.?

Physics = correlations
Richard Feynman

Astronomers
Rotation curve
Tidal streams
Gas flaring

Astrophysics
Cosmics
Gamma rays

Cosmology
23%DM, thermal history of WIMPs
Annihilation x-section
Tidal disruption of dwarf satellites

Particle Physics
Gamma ray spectra
for BG + DMA

Wim de Boer, Karlsruhe
PPC08, Albuquerque, May. 21, 2008
Comparison of convection and diffusion dominated propagation

**Convection dominated**

**Diffusion dominated**

**Summary:** preferred propagation perp. to disc reduces contribution of charged particles from DMA by large factor and can be consistent with B/C and $^{10}\text{Be}/^{9}\text{Be}$.
Positron spectrum can be tuned to arbitrary shape by Galactic Magnetic Fields (constrained by synchrotron maps).
Shape of Haze perfectly consistent with EGRET excess
Magnitude of Haze has large uncertainties from B-field
towards Galactic centre and spectral shape of electrons.
Three Reasons to Think the WMAP Haze is produced by Dark Matter

1) Angular distribution of the haze matches that found for a cusped halo profile, with \( \rho \propto R^{-1.2} \)

2) Electron/positron spectrum from ~100 GeV to multi-TeV WIMP annihilations is consistent with haze spectrum

3) For 100-1000 GeV WIMP, the annihilation cross section needed to produce the measured intensity of the haze is within a factor of 2-3 of the value needed to generate the density of dark matter thermally (no boost factors are required)

Hooper, G. Dobler and D. Finkbeiner, arXiv:0705.3655

Problem: large excess since they ignore DMA signal in foreground

astro-ph/0705.009
Phys.Rev. Lett..95:209001, 2005,
What about Supersymmetry?

Assume mSUGRA

5 parameters: $m_0$, $m_{1/2}$, $\tan b$, $A$, sign $\mu$
EGRET excess interpreted as DM consistent with WMAP, Supergravity and electroweak constraints

- Stau coannihilation
- Too large boost factor for EGRET
- LSP largely Bino \( \Rightarrow \) DM may be supersymmetric partner of CMB

Charginos, neutralinos and gluinos light

Wim de Boer, Karlsruhe
PPCO8, Albuquerque, May 21, 2008
Summary

Three independent observations prefer convection dominated propagation towards centre (INTEGRAL 511 keV large B/D ratio, ROSAT X-Ray maps and EGRET small gradient in Galactic Gammas.)

This implies FEW CHARGED PARTICLES FROM DMA from centre!!!

Modified GALPROP for convection dominated propagation perfectly describes ALL CR observations, if DMA is included, i.e.
- The EGRET excess,
- No HEAT excess
- No antiproton deficiency or excess
- No 511 keV large bulge/disk ratio
- WMAP Haze consistent with EGRET excess

EGRET ringlike excess independently confirmed by:
- Change of slope in rotation curve
- S-shape in gas flaring curve
- N-Body simulation of Canis Major tidal streams

Let’s wait for GLAST and LHC if they confirm this textbook picture of DMA with a 50-70 GeV WIMP.
BACKUP SLIDES
**The Likely Cause of the EGRET GeV Anomaly and its Implications**, F.W. Stecker S. D. Hunter D. A. Kniffen

arXiv:0705.4311

“This all-sky analysis confirms that the GeV anomaly is uniform over the entire sky. The lack of any structure in the anomaly related to the Galactic plane, galactic center, anti-center or halo, strongly indicates that the GeV anomaly is due to a systematic error in the EGRET calibration rather than being a real astronomical effect.”

“There are serious problems with the DM hypothesis: (1) The same process of dark matter annihilation would produce a flux of cosmic-ray antiprotons which is incompatible with the measured value [28]. (2) The celestial γ-ray distribution from dark matter annihilation would be both highly asymmetric and clumped [29]. This is again in direct contradiction with isotropy of the anomaly.”

Wrong statements:

a) Excess NOT uniform
b) Excess EXACTLY distributed as expected from isothermal DM
c) Antiprotons not a problem for different propagation in halo and disk
d) Suggested efficiency corr. does NOT work in all sky dir.

Note: online calibration paper suggests 6% errors, not 85%
EGRET excess interpreted as DM consistent with WMAP, Supergravity and electroweak constraints

Stau coannihilation

Charginos, neutralinos and gluinos light

LSP largely Bino ⇒ DM may be supersymmetric partner of CMB
Electron and proton CR spectra

CDM Electrons

CR Protons

Flux [m$^2$ sr$^{-1}$ s$^{-1}$ GeV$^{-1}$]

Energy/nucleon [GeV]

- Total
- $\sigma m$
- $\sigma r$
- electron injection spectrum
  (arbitrary normalization)

- CR Protons
- nuclei injection spectrum
  (arbitrary normalization)