Do Galactic Gamma Rays reveal our Galaxy’s DM?

Idea:

Thermal relics disappeared by annihilation.
(From WMAP Annihilation cross section $\langle \sigma v \rangle = 2 \times 10^{-27} / \Omega h^2$)

Annihilation into Quarks with this $\sigma$-section should yield large amount of Gamma Rays (37γ/s/Annihilation from LEP data)

Gamma spectrum from DMA significantly harder than dominant background from inelastic pp collisions.

Background shape KNOWN from fixed target experiments, DMA Gamma Ray shape KNOWN from LEP data

EGRET Data indeed shows such an expected excess with correct spectral SHAPE IN ALL SKY directions and INTENSITY of excess allows to measure DM distribution in GALAXY. Then one knows MASS distribution of DM and visible matter and can calculate ROTATION CURVE.

IF GAMMA RAYS indeed originate from DMA, then this can be proven by calculating shape of RC from Gamma Rays!
Thermal history of WIMP's as thermal relic

Thermal equilibrium abundance

Actual abundance

\( T >> M: \quad f + \bar{f} \to M + \bar{M}; \quad M + \bar{M} \to f + \bar{f} \)

\( T < M: \quad M + \bar{M} \to f + \bar{f} \)

\( T = M/22: \quad M \) decoupled, stable density (when annihilation rate \( \cong \) expansion-rate, i.e. \( \Gamma = \langle \sigma v \rangle n_\chi(x_{fr}) \cong H(x_{fr})! \))

\( \Omega h^2 = 0.113 \pm 0.009 \to \langle \sigma v \rangle = 2.10^{-26} \text{ cm}^3/\text{s} \)

DM increases in Galaxies:

\( \approx 1 \) WIMP/coffee cup \( \approx 10^5 \langle \rho \rangle \).

DMA (\( \propto \rho^2 \)) restarts again...

Annihilation into lighter particles, like Quarks and Leptons -> \( \pi_0 \)'s -> Gammas!

Only assumption in this analysis:

WIMP = THERMAL RELIC!

Jungmann, Kamionkowski, Griest, PR 1995
EGRET on CGRO (Compton Gamma Ray Observ.)
Data publicly available from NASA archive

EGRET Parameter:
Energy reach: 0.02–30 GeV
Energy resolution: ~20%
Effective area: 1500 cm²
Angular resolution: <0.5°

EGRET Results:
Catalogue of point sources
Excess of diffuse gamma rays

This talk:
Spectrum of excess consistent with DMA of 60 GeV
WIMP in all sky directions
Intensity of excess in different sky directions
Explains shape of rotation curve
DM Annihilation in Supersymmetry

\[ \chi \rightarrow f \chi \]
\[ \chi \rightarrow \tilde{f} \]
\[ f \rightarrow A \tilde{f} \]
\[ A \rightarrow Z \chi \]
\[ Z \rightarrow W \chi \]
\[ W \rightarrow \chi^0 \]

\[ \chi^\pm \rightarrow \chi^0 Z \]

\[ \sigma v = 2 \times 10^{-26} \text{ cm}^3/\text{s} \]

Quark-Fragmentation known!
Hence spectra of positrons, Gammas and antiprotons known!

\[ \approx 37 \text{ gammas} \]
The EGRET excess of diffuse galactic gamma rays without and with DM annihilation

If normalization free, only relative point-to-point errors of $\leq 7\%$ important, not absolute normalization error of 15%. Statistical errors negligible.

Fit only KNOWN shapes of BG + DMA, i.e. 1 or 2 parameter fit NO GALACTIC models needed. Propagation of gammas straightforward
Background + signal describe EGRET data!

Blue: background uncertainty

Blue: WIMP mass uncertainty
Fits for 180 instead of 6 regions

180 regions:
8° in longitude ⇒ 45 bins
4 bins in latitude ⇒ 0° < |b| < 5°
5° < |b| < 10°
10° < |b| < 20°
20° < |b| < 90°
⇒
4x45 = 180 bins
Dark Matter distribution

Expected Profile

Observed Profile

Halo profile

Rotation Curve

Normalize to solar velocity of 220 km/s

v^2 \propto M/r = \text{const.}

\rho \propto 1/r^2

Divergent for r=0?

NFW \propto 1/r

Isotherm const.

Halo profile

Outer Ring

Inner Ring

totalDM

1/r^2 halo

disk

bulge

Inner Ring

Outer Ring

CO

HI

HI, HII

luminous disk

bulge

inner ring

outer ring

June 14, 2006
SUSY06, Irvine
W. de Boer, Univ. Karlsruhe
Rotation curve of Milky Way

Honma & Sofue (97)
Schneider & Terzian (83)
Brand & Blitz (93)
Do other galaxies have bumps in rotation curves?

Sofue & Honma
Inner ring coincides with ring of dust and $\text{H}_2$ - gravitational potential well by DM
7 Physics Questions answered SIMULTANEOUSLY by this analysis

• Astrophysicists:
  What is the origin of “GeV excess” of diffuse Galactic Gamma Rays? A: DM annihilation

• Astronomers:
  Why a change of slope in the galactic rotation curve at $R_0 \approx 11$ kpc? A: DM substructure

  Why ring of stars at 14 kpc?

  Why ring of molecular hydrogen at 4 kpc?

• Cosmologists: How is DM annihilating? A: into quark pairs
  How is Cold Dark Matter distributed? A: isothermal cored profile+substructure

• Particle physicists:
  Is DM annihilating as expected in Supersymmetry? A: Cross sections perfectly consistent with mSUGRA for light gauginos, heavy squarks/sleptons
Bergstrom astro-ph/0603632: Abstract:

we investigate the viability of the model using the DarkSUSY package to compute the gamma-ray and antiproton fluxes. We are able to show that their (=WdB et al) model is excluded by a wide margin from the measured flux of antiprotons.

Problem with DarkSUSY (DS):

1) Flux of antiprotons/gamma in DarkSUSY: $O(1)$ from DMA. However, $O(10^{-3})$ from LEP data
   Reason: DS has diffusion box with isotropic diffusion -> DMA fills up box with high density of antiprotons
2) More realistic models have anisotropic diffusion.
   E.g. spiral galaxies have magnetic fields perpendicular to disk -> antiprotons may spiral quickly out of Galaxy.
Magnetic fields observed in spiral galaxies

A few uG perpendicular to disc: Diffusion preferentially $\perp$ to disc? Alternativ: strong convection

A few $\mu$G along spiral arms: Can lead to slow radial diffusion

Isotropic diffusion assumes randomly oriented magnetic turbulences. Preferred magnetic field directions -> anisotropic diffusion
Preliminary results from GALPROP with isotropic and anisotropic propagation

**Antiprotons**

**B/C ratio**

Summary: with anisotropic propagation you can send charged particles wherever you want and still be consistent with B/C and $^{10}\text{Be}/^{9}\text{Be}$
Cosmic clocks: $^{10}\text{Be}/^{9}\text{Be}$
Future: Direct DM Searches

Spin-independent

- DAMA
- ZEPLIN
- CDMS
- Edelweiss

Spin-dependent

- DAMA
- ZEPLIN
- CDMS
- Edelweiss

Predictions from EGRET data assuming Supersymmetry
Summary

DMA interpretation of EGRET excess (> 10 $\sigma$!) can:
1) determine WIMP mass (50-100 GeV)
2) determine DM halo profile
3) explain why excess has same shape in all directions

Reconstruction of rotation curve from GAMMA RAYS ->
EGRET excess = Tracer of Dark Matter!

Results practical model independent, since only
KNOWN shapes of signal and background are used,
NOT model dependent calculations of absolute fluxes.
Halo shape also practical independent of experimental
uncertainties, since only relative efficiencies
for 180 sky directions important.

Models WITHOUT DM cannot explain the rotation curve
Halo profile without rings

DISC

10° < b < 20°

5° < b < 10°

20° < b < 90°

R [kpc]

Sonne long GC
Halo profile with rings

DISC

$10^0 < b < 20^0$

$5^0 < b < 10^0$

$20^0 < b < 90^0$
Objections from particle physicists

Particle physicists:
you assume spectrum of protons to be the same everywhere in galaxy. How can you be sure?

Answers:
1) If centre of galaxy would be different because of SN there is no reason to get same shape of excess in outer galaxy (very few SN)

2) Diffusion time much shorter than energy loss times -> hard to image strong changes in spectral shape.
Objections from astrophysicists

Astrophysicists: hard to believe that collisionless DM, i.e. particles which experience only gravity, is self-annihilating and that particle physicists even believe to know spectral shapes of final states! They prefer models with modified CR spectra outside solar system

Answer: too bad, but “optimized models” do not work too well if one considers all sky directions
Objections from astronomers

Astronomers: outer rotation curve determined with different method than inner rotation curve. Hard to compare. Furthermore slope depends on distance to centre ($R_0$)

Answer: First points of outer rot. curve in perfect agreement with inner rot. curve. CHANGE in slope for any $R_0$

Black hole at centre: $R_0=8.0\pm0.4$ kpc