Evidence for Dark Matter Annihilation

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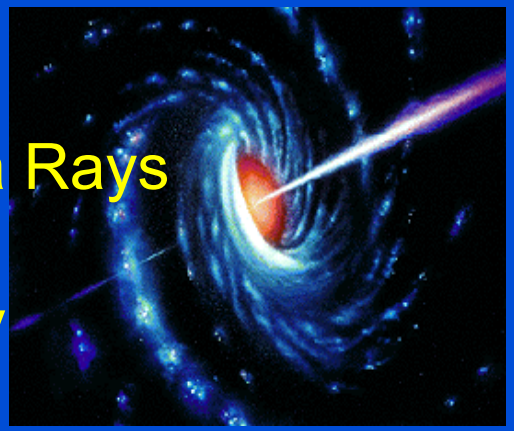
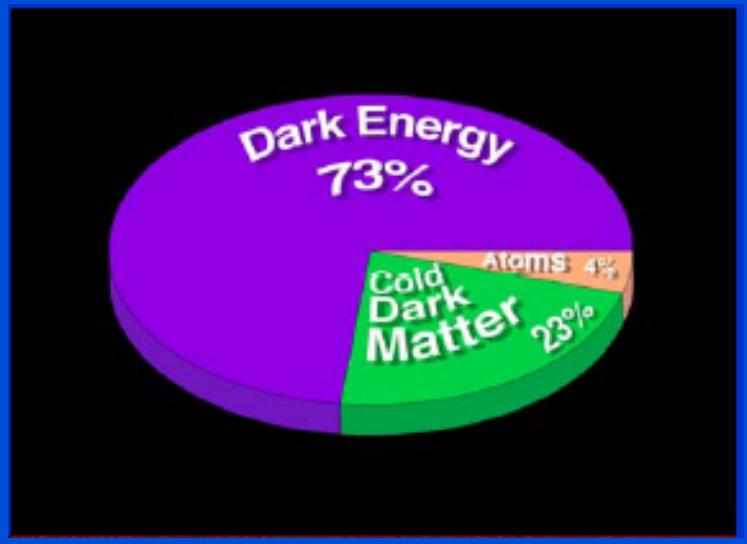
Astro-ph/0408272

Outline

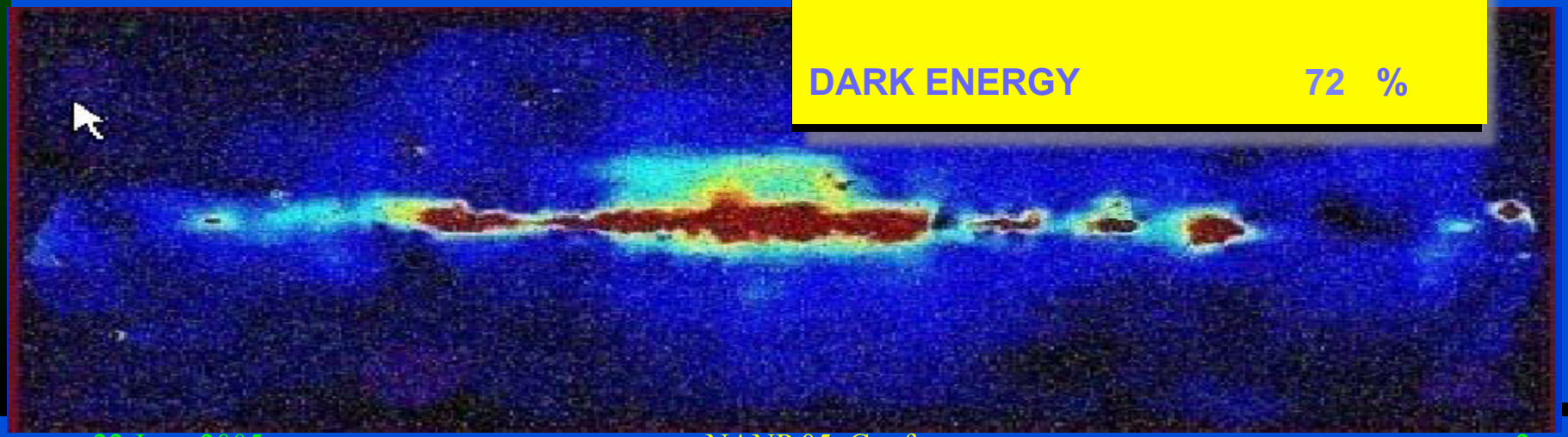
- Dark Matter in the Universe
- EGRET data on Diffuse Gamma Rays
- DM Halo Profile
- Rotation Curve of the Milky Way
- SUSY Dark Matter
- Conclusions



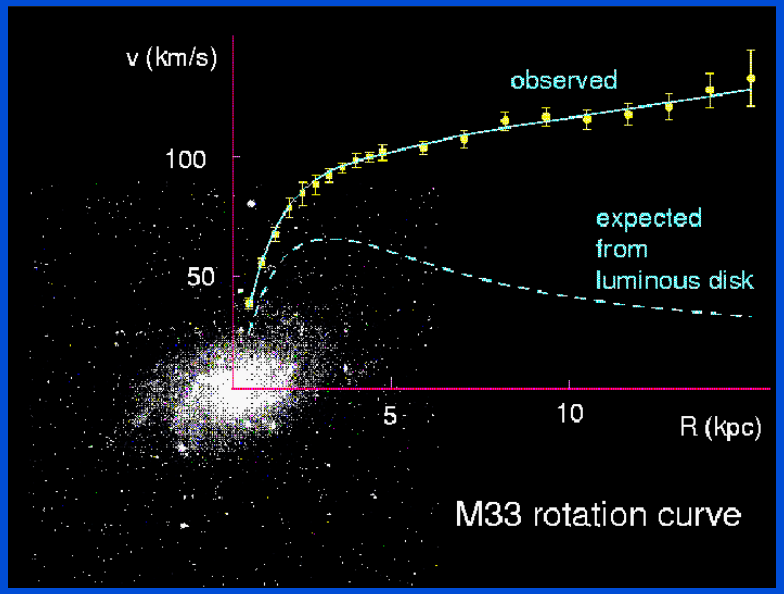
MATTER AND ENERGY CONTENT OF THE UNIVERSE



HEAVY ELEMENTS	0.03 %
MASSIVE NEUTRINOS	0.3 %
STARS	0.5 %
H AND He	4 %
DARK MATTER	23 %
DARK ENERGY	72 %



EVIDENCE FOR THE DARK MATTER



THE FLAT ROTATION CURVES OF SPIRAL GALAXIES PROVIDE THE MOST DIRECT EVIDENCE FOR THE EXISTENCE OF LARGE AMOUNT OF THE DARK MATTER.

SPIRAL GALAXIES CONSIST OF A CENTRAL BULGE AND A VERY THIN DISC, AND SURROUNDED BY AN APPROXIMATELY SPHERICAL HALO OF DARK MATTER

Physics Problems

- **Cosmologists:**

  What is CDM and Dark Energy made of?
- **Particle physicists:**

  Where are the Supersymmetric Particles?
- **Astrophysicists:**

  What is the origin of excess of diffuse Galactic Gamma Rays?
- **Astronomers:**

  Why a change of slope in the galactic rotation curve at 1.1 R_0?

  Why ring of stars at 14 kpc so stable?

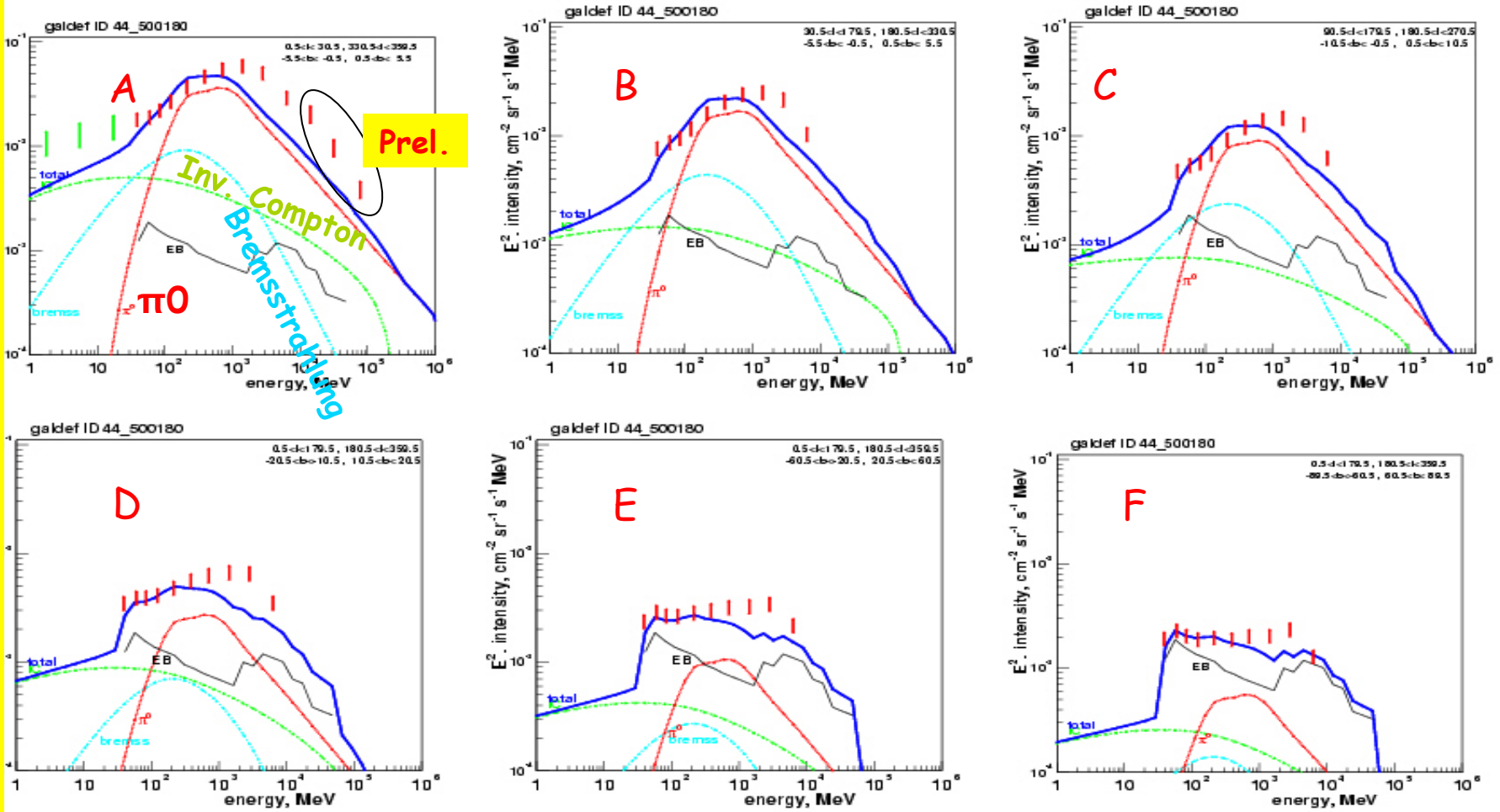
  Why ring of molecular hydrogen at 4 kpc so stable?

Proposed Solution

- DM made of WIMPS annihilating into quarks, which yield hard gammas from π_0 decays
- WIMP has properties of supersymmetric lightest particle
- From SPECTRUM of excess of gamma rays DM: WIMP mass 50-100 GeV
- Gamma excess correlated with ring of stars at 14-18 kpc thought to originate from infall of a dwarf galaxy and ring of DM at 4 kpc stabilizes ring of hydrogen
- From INTENSITY: halo distribution and rotation curve

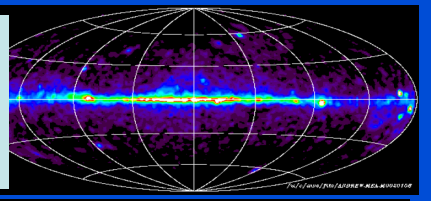
Excess of Diffuse Gamma Rays above 1 GeV as measured by EGRET satellite (9 yrs of data)

Strong, Moskalenko, Reimer, to be published



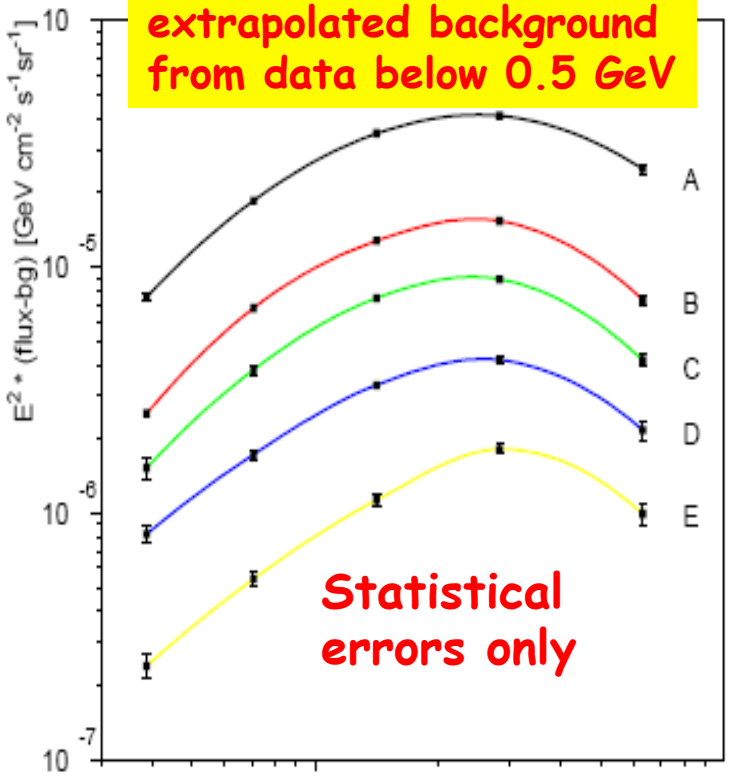
A: inner Galaxy (l=±30⁰, |b|<5⁰)
B: Galactic plane avoiding A
C: Outer Galaxy

D: low latitude (10-20⁰)
E: intermediate lat. (20-60⁰)
F: Galactic poles (60-90⁰)

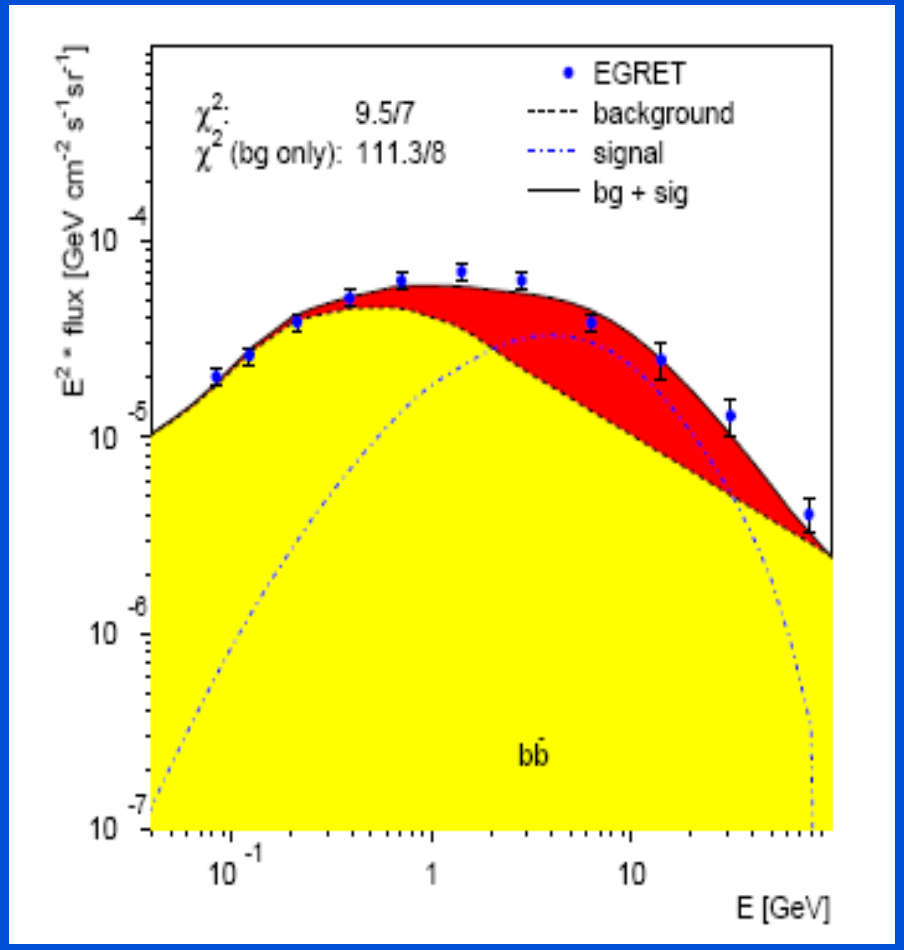


Excess of Diffuse Gamma Rays has same spectrum in all directions compatible with WIMP mass of 50-100 GeV

Egret Excess above extrapolated background from data below 0.5 GeV

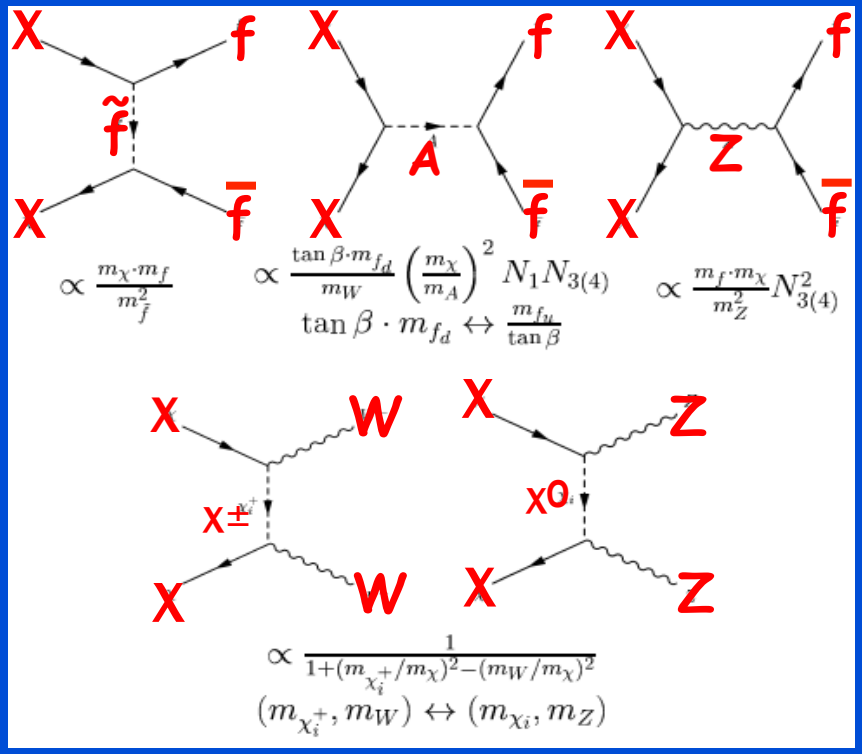


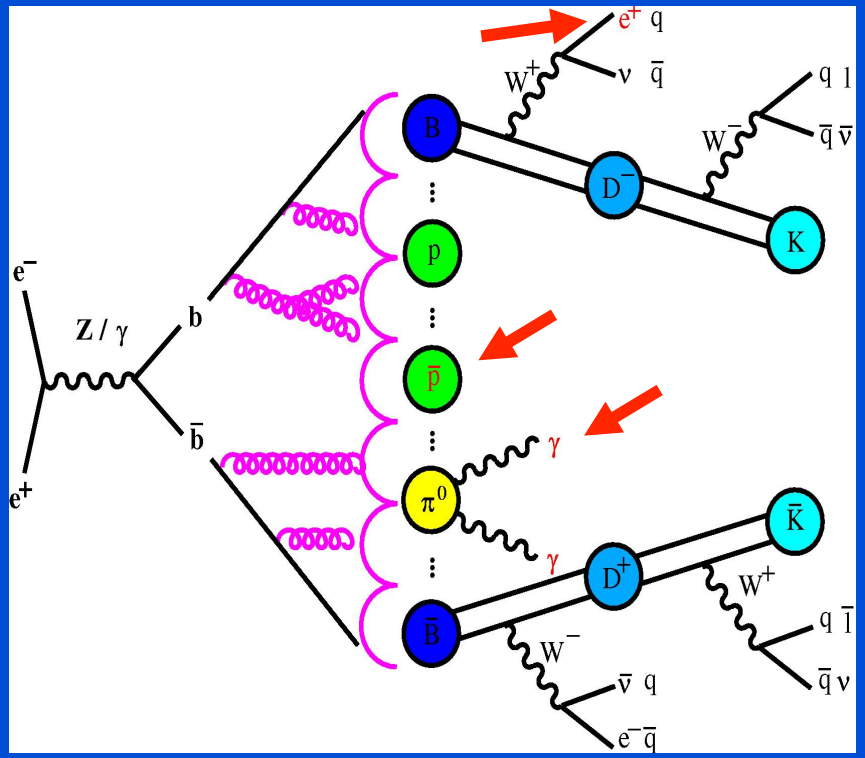
Excess same shape in all regions implying same source everywhere



Important: if experiment measures gamma rays down to 0.1 GeV, then normalizations of DM annihihilation and background can both be left free, so one is not sensitive to absolute background estimates, BUT ONLY TO THE SHAPE, which is much better known.

Neutralino Annihilation Final States

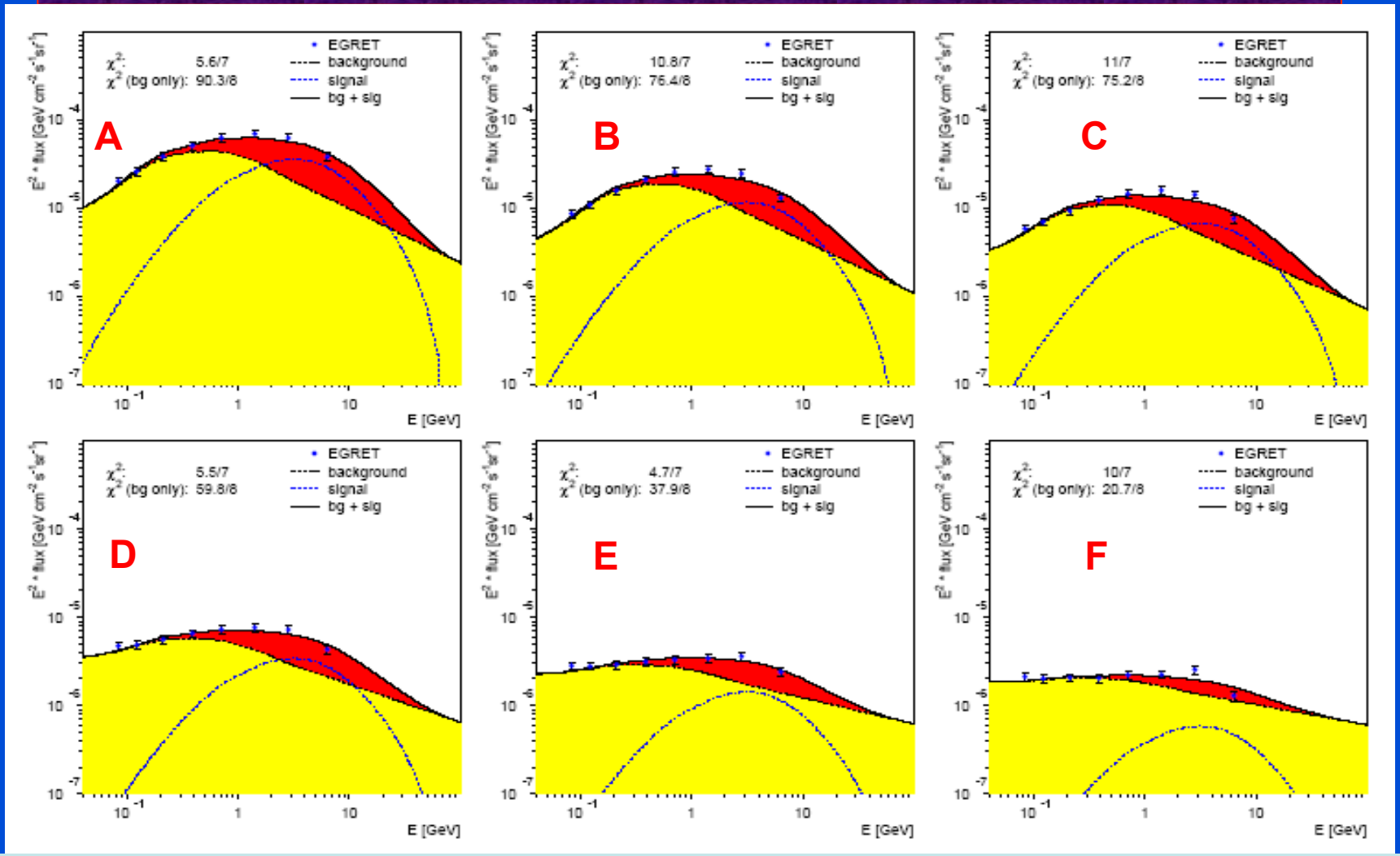




Dominant Diagram for WMAP cross section:
X + X ➔ A ➔ b bbar quark pair

B-fragmentation well studied at LEP! Yield and spectra of positrons, gammas and antiprotons well known!

Diffuse Gamma Rays for different sky regions



DMA ~ Boostfactor $\langle \rho^2 \rangle$ If boost factor, i.e. clustering, similar in all directions, then signal strength determines DM density ρ

Fit results of halo parameters

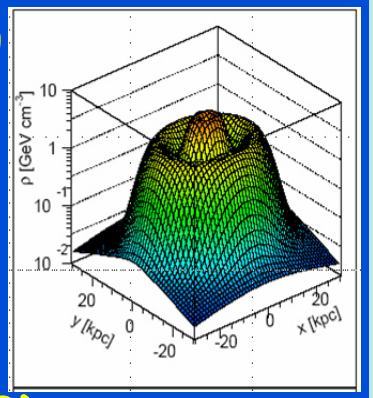
Gamma Ray Flux: (<σv> from WMAP)

$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

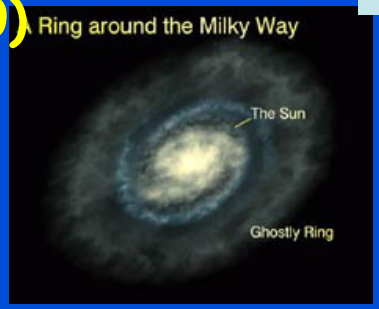
$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N} \rho_n \exp\left(-\frac{(\tilde{r}_{gc}-Rn)^2}{2\sigma_{Rn}^2} - \frac{(z_n)^2}{2\sigma_{z_n}^2}\right)$$

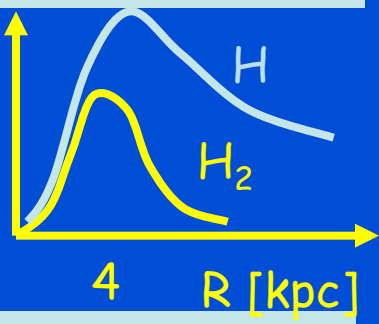
~ $1/r^2$ 2 Gaussian rings

Parameter	Value	Parameter	Value
α	2	R_a	4.3 kpc
β	2	$\sigma_{R,a}$	3.4 kpc
γ	0	$\sigma_{z,a}$	0.3 kpc
R_0	8.5 kpc	ρ_b	2.3 GeV cm^{-3}
a	4 kpc	R_b	14 kpc
ρ_0	0.47 GeV cm^{-3}	$\sigma_{R,b}$	2.1 kpc
ρ_a	3.3 GeV cm^{-3}	$\sigma_{z,b}$	1.3 kpc
b/a	0.9	c/a	0.8



Enhancement of rings over $1/r^2$ profile 2 and 7, respectively. Mass in rings 1.6 and 0.3% of total DM





14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy (Yanny, Ibata, …..)

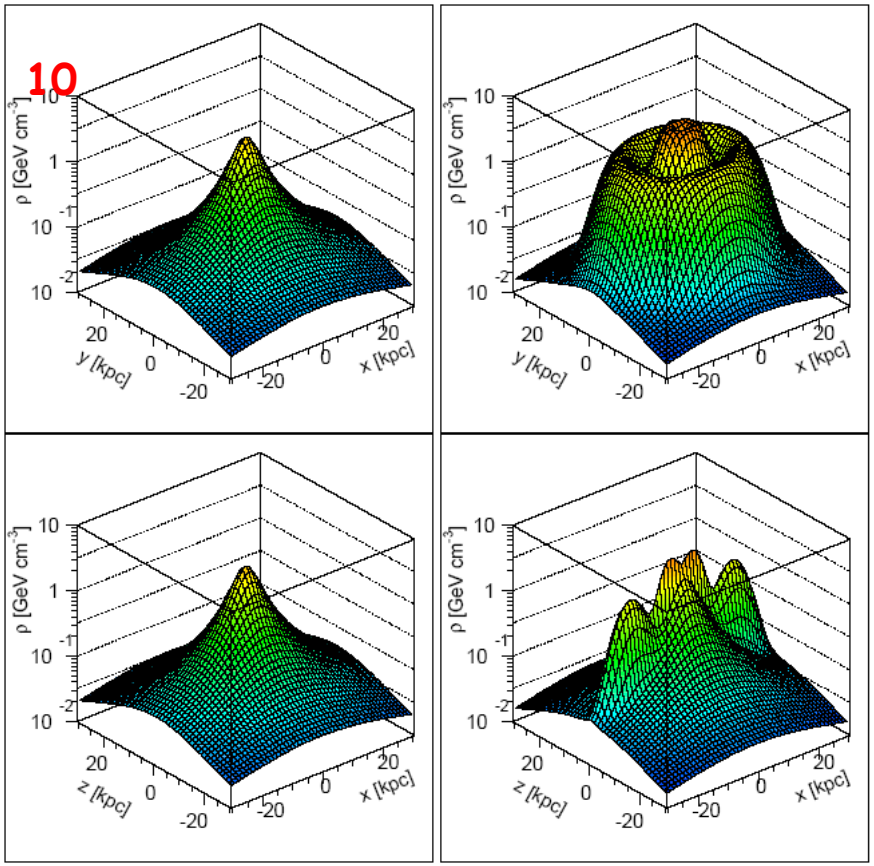
4 kpc coincides with ring of neutral hydrogen molecules!

Halo profiles

Isothermal cored profile

WITHOUT rings

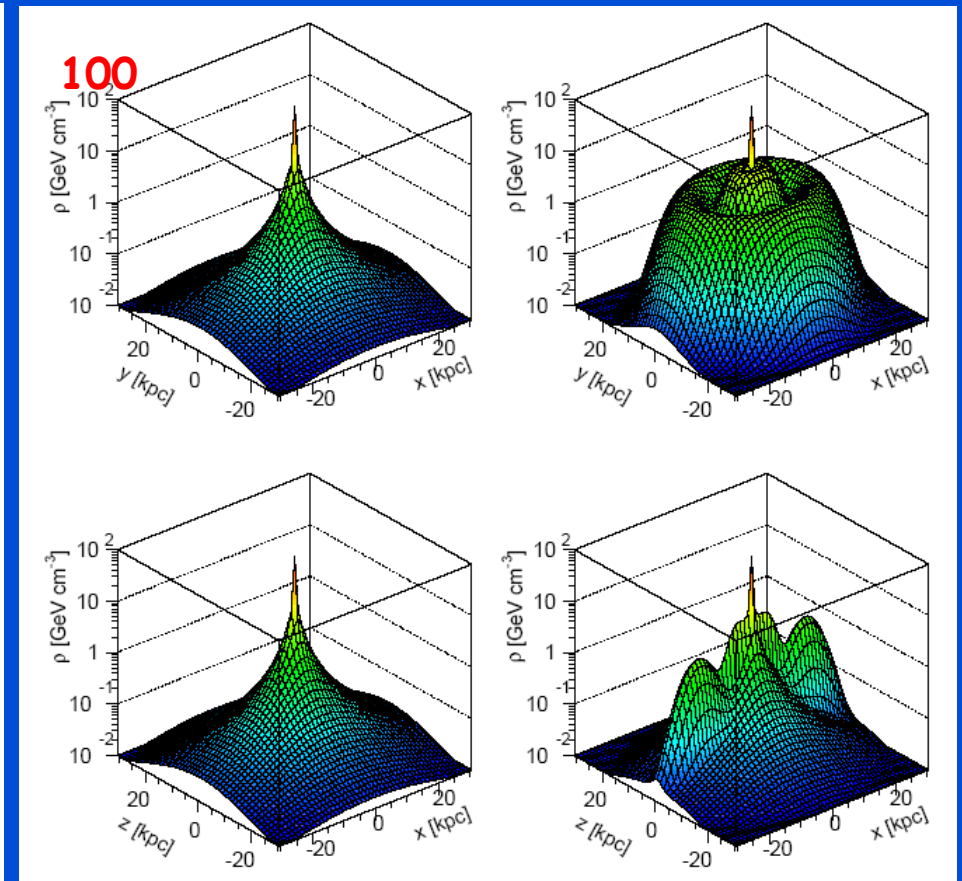
WITH rings



NFW cuspy profile

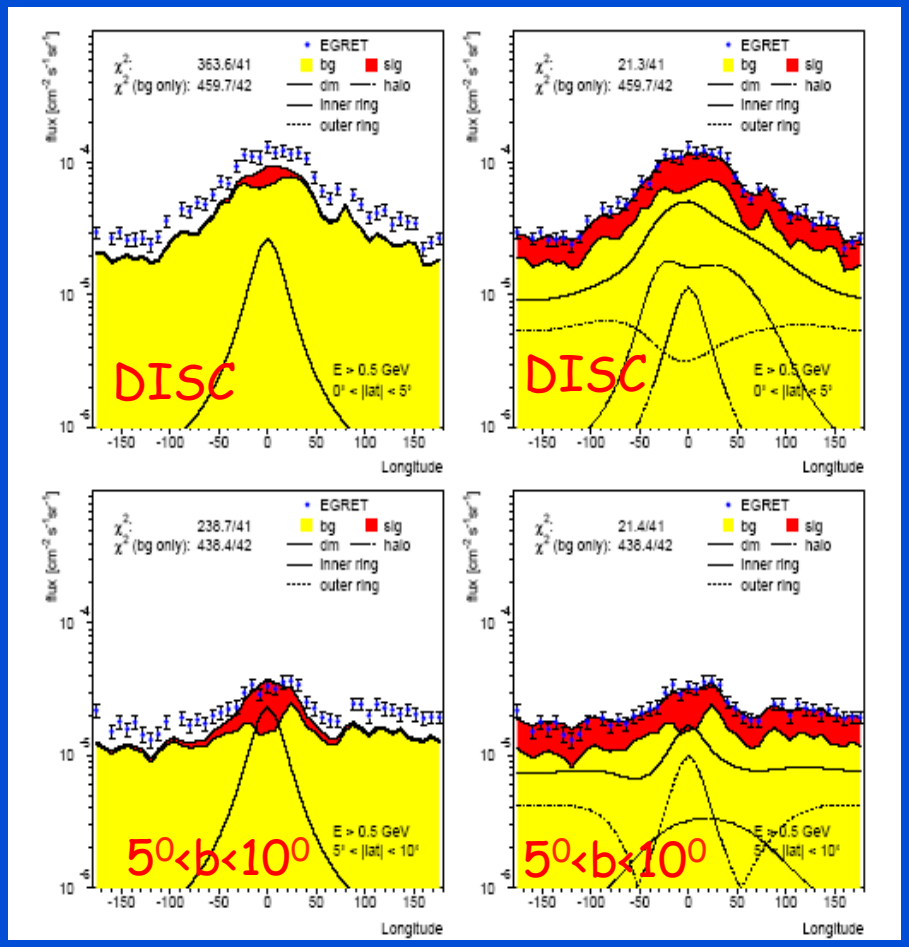
WITHOUT rings

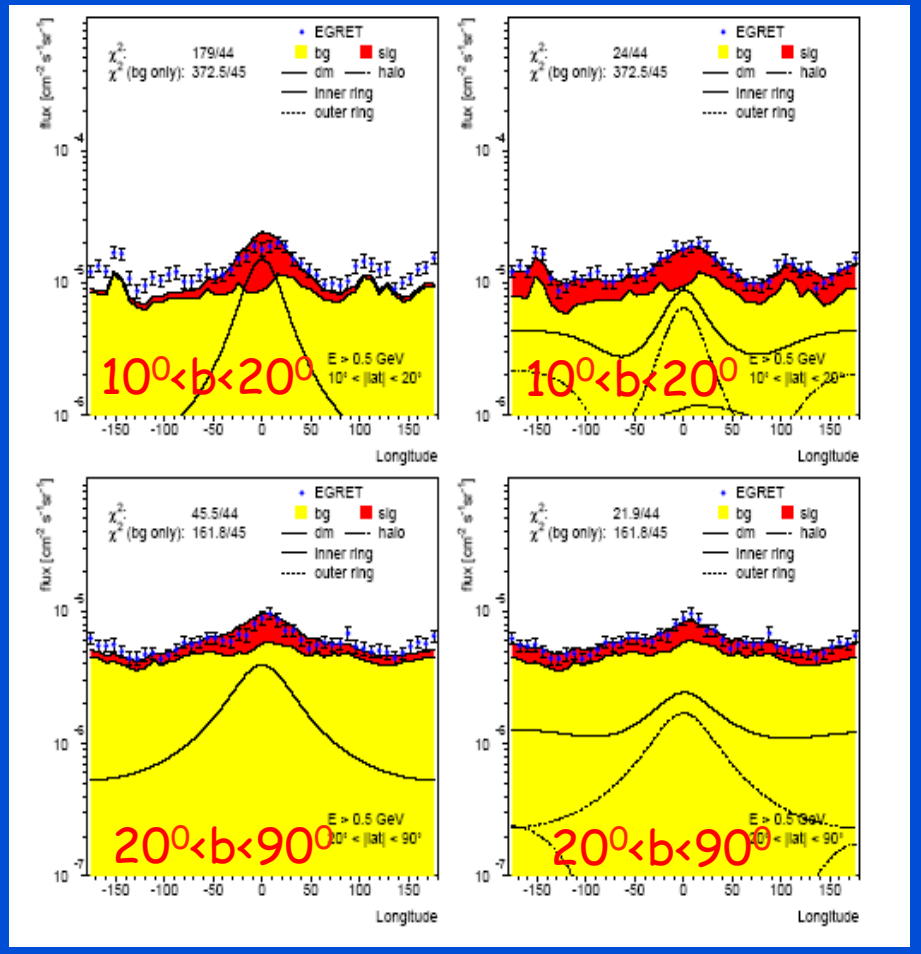
WITH rings



Longitude fits for isothermal (cored) profile

WITHOUT rings | WITH 2 rings | WITHOUT rings | WITH 2 rings

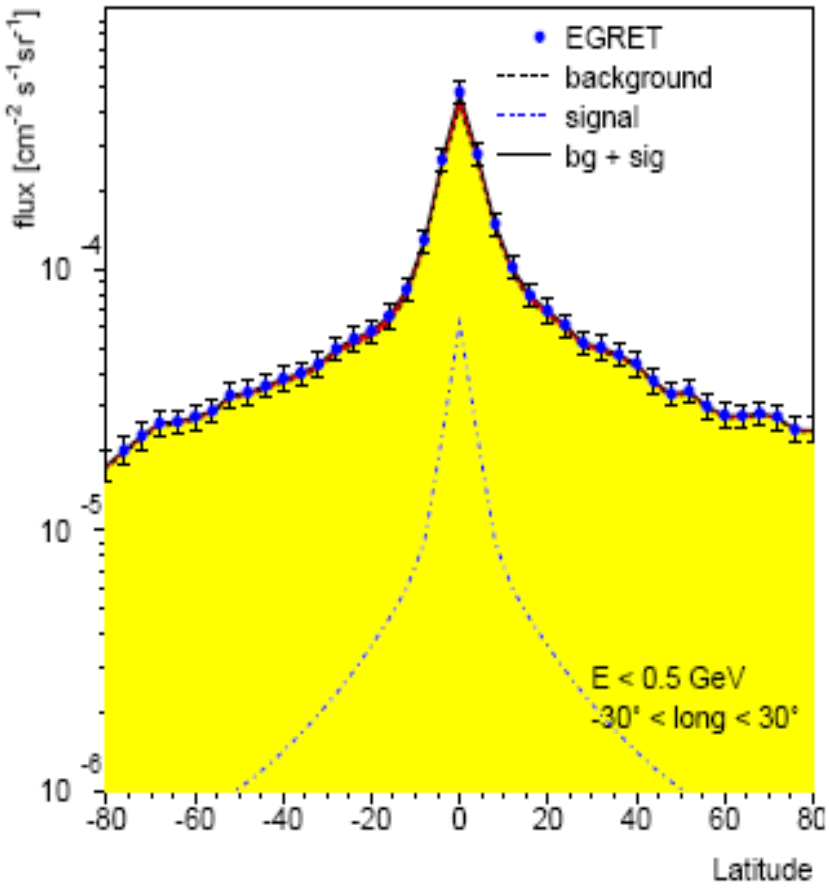




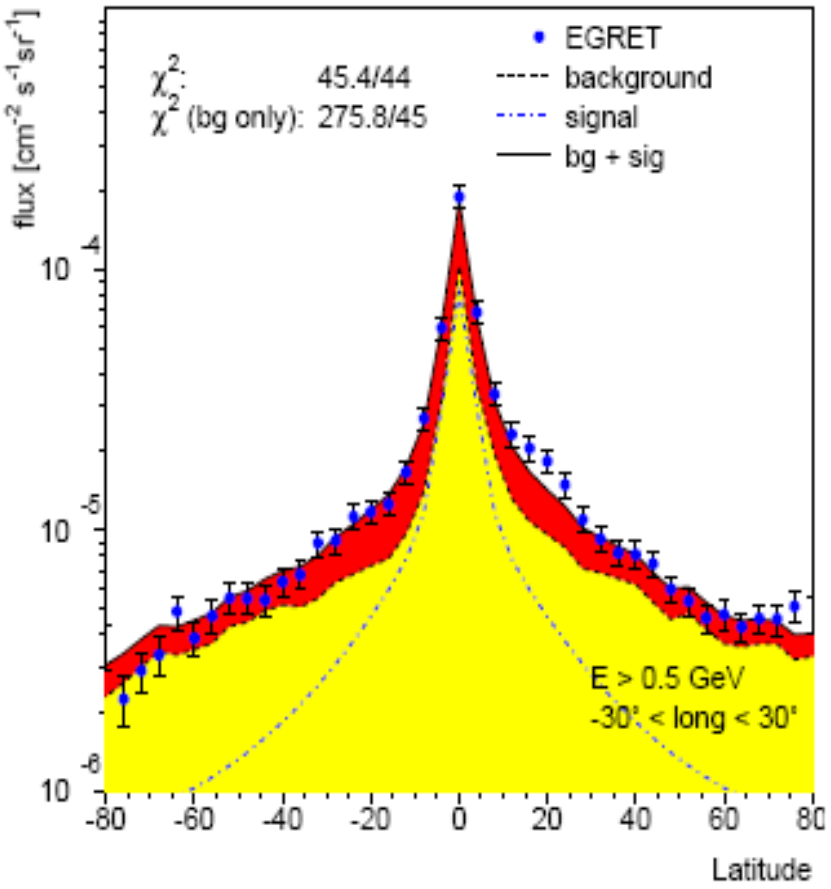
Halo parameters from fit to 180 sky directions: 4 long. profiles for latitudes <5⁰, 5⁰<b<10⁰, 10⁰<b<20⁰, 20⁰<b<90⁰ (=4x45=180 directions)

Latitude fits for isoth. Profile with |long|<30⁰

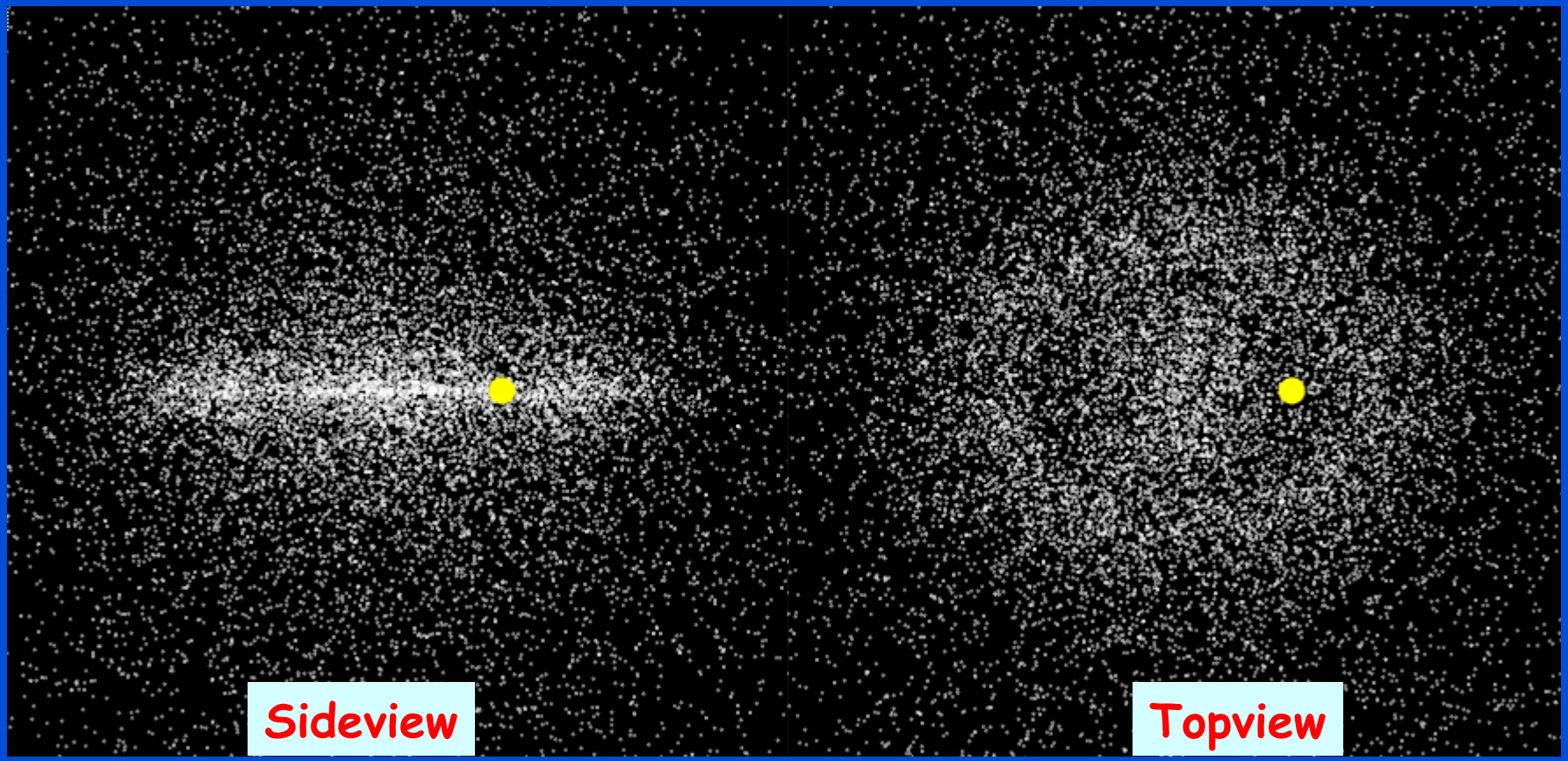
0.1 < Eγ < 0.5 GeV



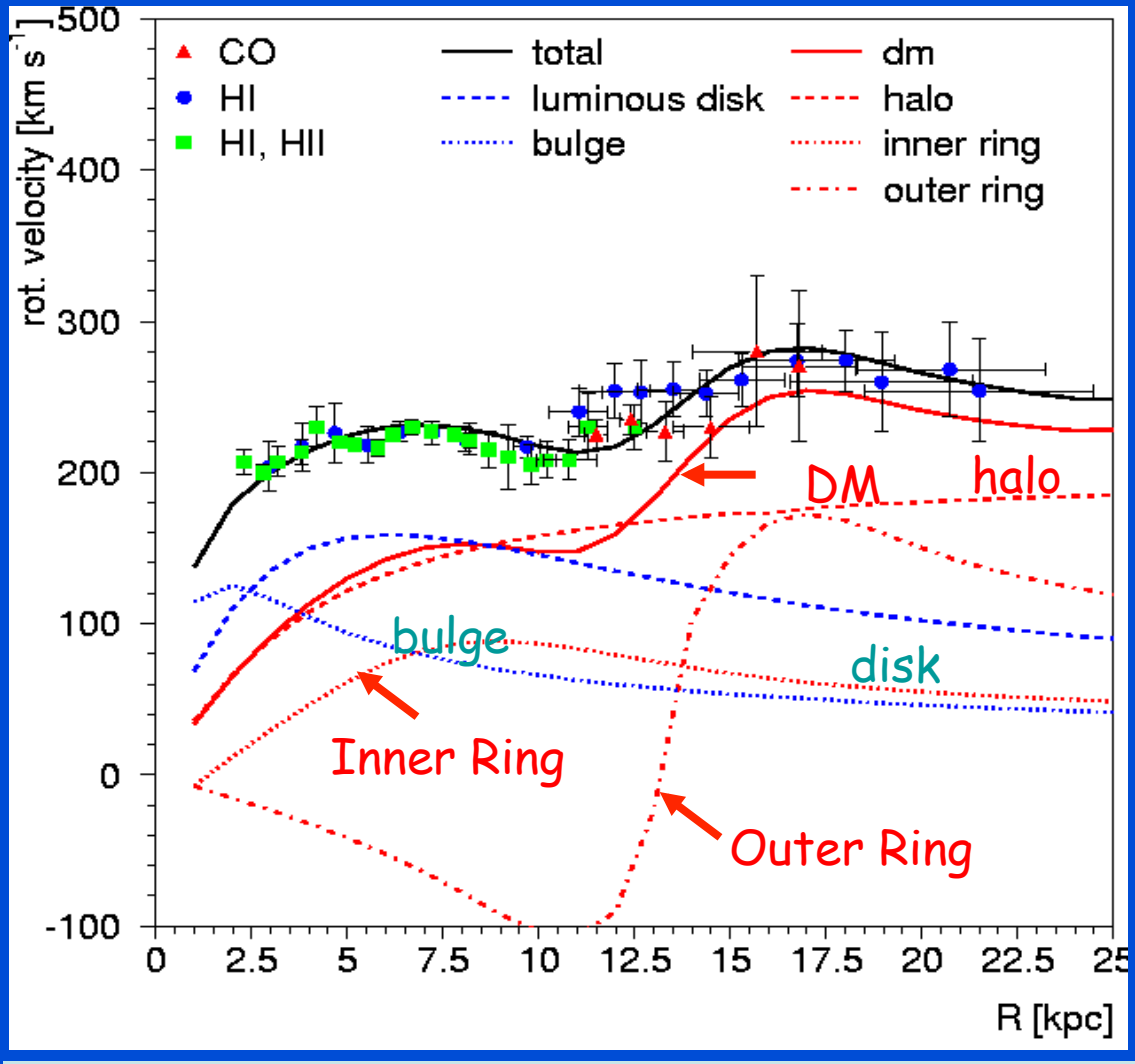
Eγ > 0.5 GeV

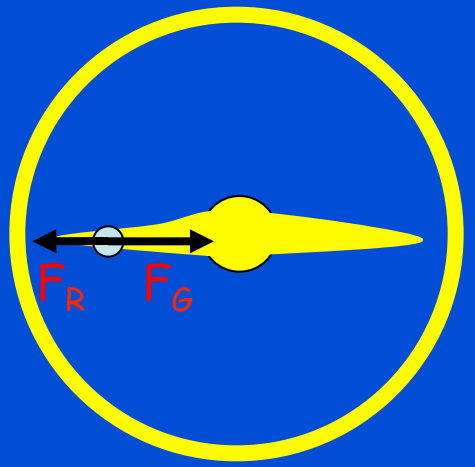


Halo density on scale of 30 kpc



Rotation curve of our galaxy





Rotation curve shows there is a ring of CDM with a mass of a few 10^{10} $M_\odot$

PARTICLE CONTENT OF THE MSSM

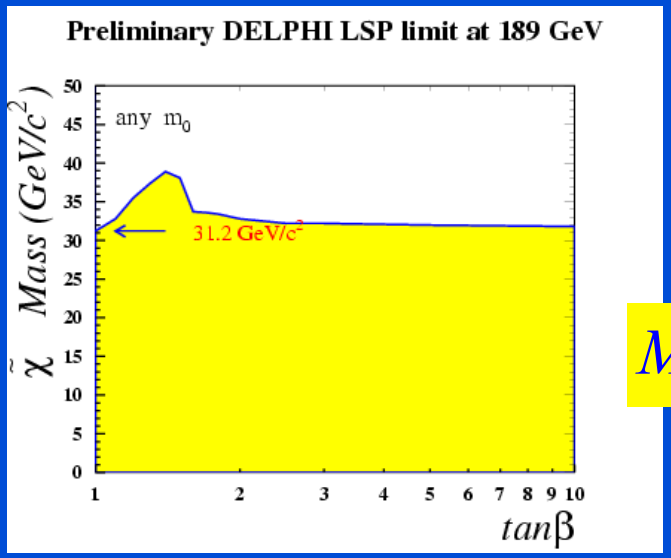
Superfield	*Bosons*	*Fermions*	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge					
G^a	*gluon* g^a	*gluino* $\tilde{g}^a$	8	1	0
V^k	*Weak* $W^k(W^{\pm},Z)$	*wino, zino* $\tilde{w}^k(\tilde{w}^{\pm},\tilde{z})$	1	3	0
V'	*Hypercharge* $B(\gamma)$	*bino* $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter					
L_i	sleptons $\tilde{L}_i = (\tilde{\nu},\tilde{e})_L$	$L_i = (\nu,e)_L$	1	2	-1
E_i	sleptons $\tilde{E}_i = \tilde{e}_R$	$E_i = e_R$	1	1	2
Q_i	squarks $\tilde{Q}_i = (\tilde{u},\tilde{d})_L$	$Q_i = (u,d)_L$	3	2	1/3
U_i	squarks $\tilde{U}_i = \tilde{u}_R$	$U_i = u_R$	3^*	1	$-4/3$
D_i	squarks $\tilde{D}_i = \tilde{d}_R$	$D_i = d_R$	3^*	1	2/3
Higgs					
H_1	H_1	higgsinos $\tilde{H}_1$	1	2	-1
H_2	H_2	higgsinos $\tilde{H}_2$	1	2	1

SUSY DARK MATTER

Neutralino = SUSY candidate for the cold Dark Matter
Neutralino = the Lightest Superparticle (LSP) = WIMP

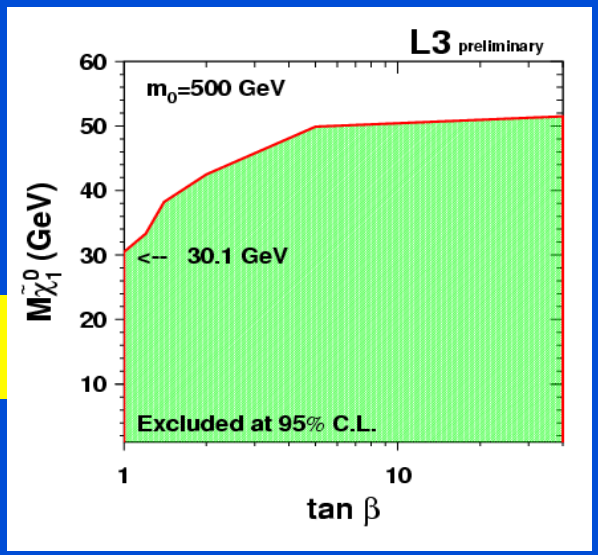
$$\tilde{\chi}^0 = N_1\tilde{\gamma} + N_2\tilde{z} + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0$$

photino zino higgsino higgsino



$$M_{\tilde{\chi}}^{exp} \geq 40 \text{ GeV}$$

$$M_{\tilde{\chi}}^{theor} = 40 \div 400 \text{ GeV}$$



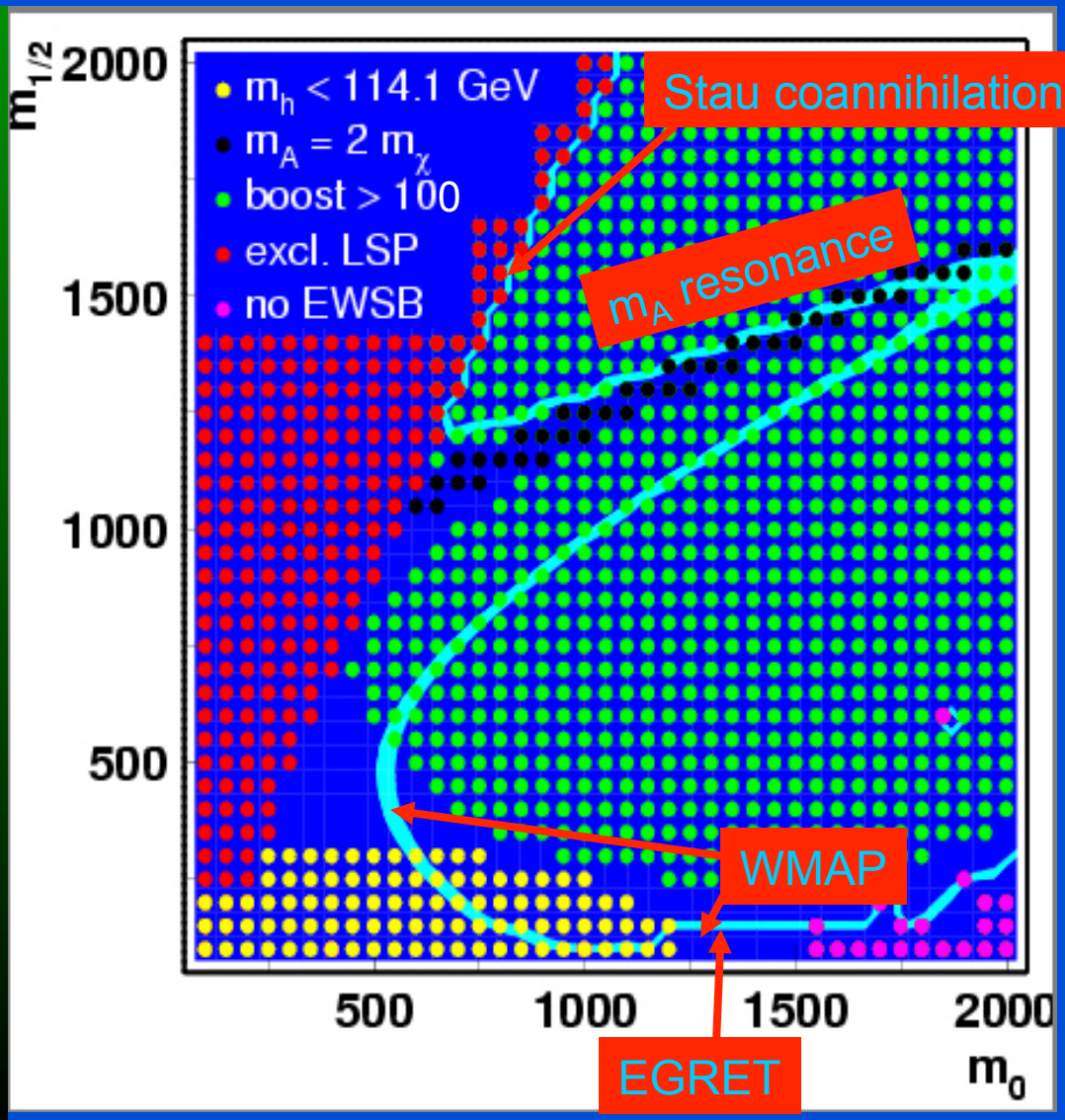
R-parity:

$$R = (-1)^{3(B-L)+2S}$$

$$R_p = +1, \; R_{\tilde{p}} = -1$$

- **Superparticles are created in pairs**
- **The lightest superparticle is stable**

EGRET excess interpreted as DM consistent with WMAP, Supergravity and electroweak constraints



MSUGRA can fulfill all constraints from WMAP, LEP, b->sγ, g-2 and EGRET simultaneously, if DM is neutralino with mass in range 50-100 GeV and squarks and sleptons are O(1 TeV)

m_0 common spin 0 mass

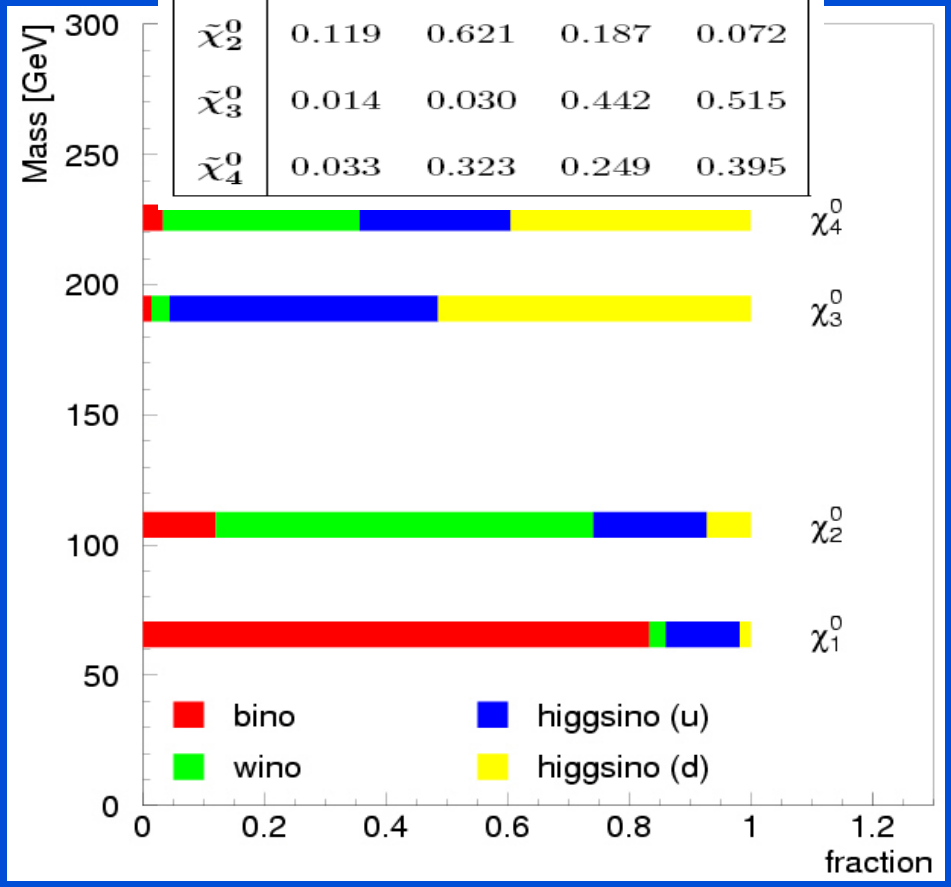
$m_{1/2}$ common spin ½ mass

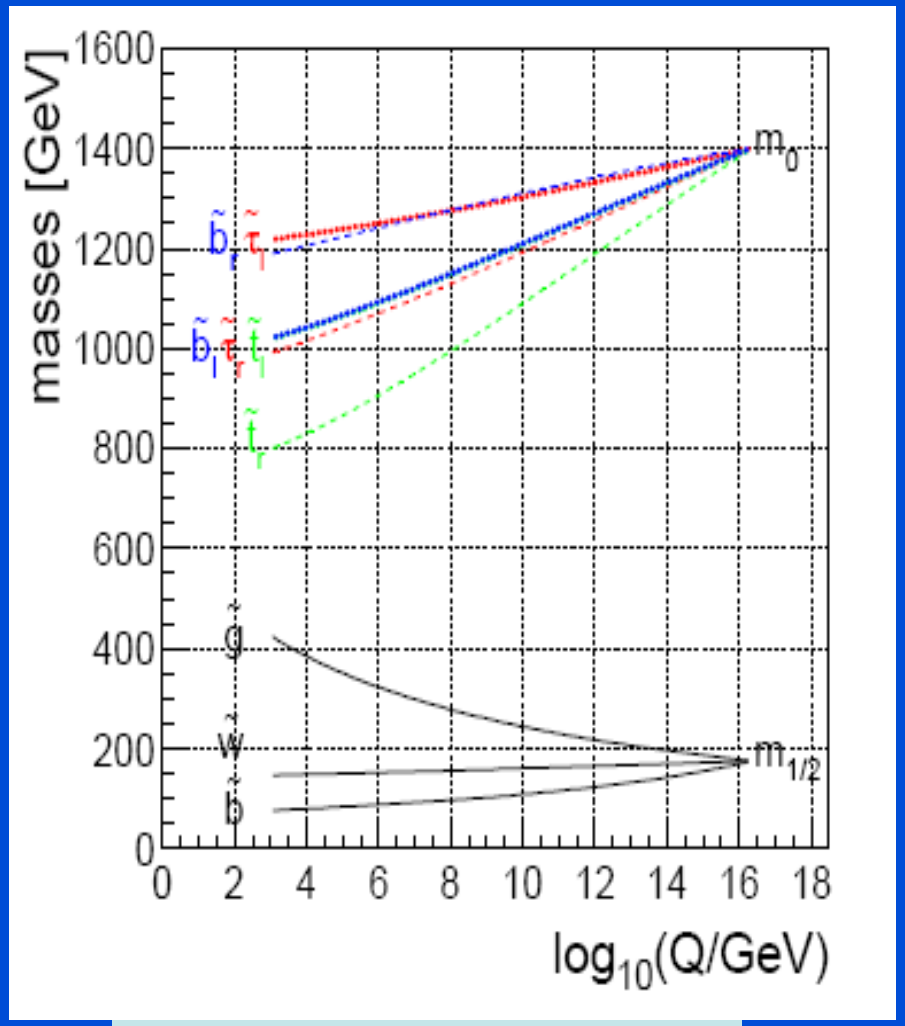
$\tan\beta = v_2/v_1$

High tanβ solution
tanβ = 50

SUSY Mass spectra in mSUGRA

	$\tilde{b}^0$	$\tilde{w}^0$	$\tilde{h}_1^0$	$\tilde{h}_2^0$
$\tilde{\chi}_1^0$	0.833	0.026	0.122	0.018
$\tilde{\chi}_2^0$	0.119	0.621	0.187	0.072
$\tilde{\chi}_3^0$	0.014	0.030	0.442	0.515
$\tilde{\chi}_4^0$	0.033	0.323	0.249	0.395



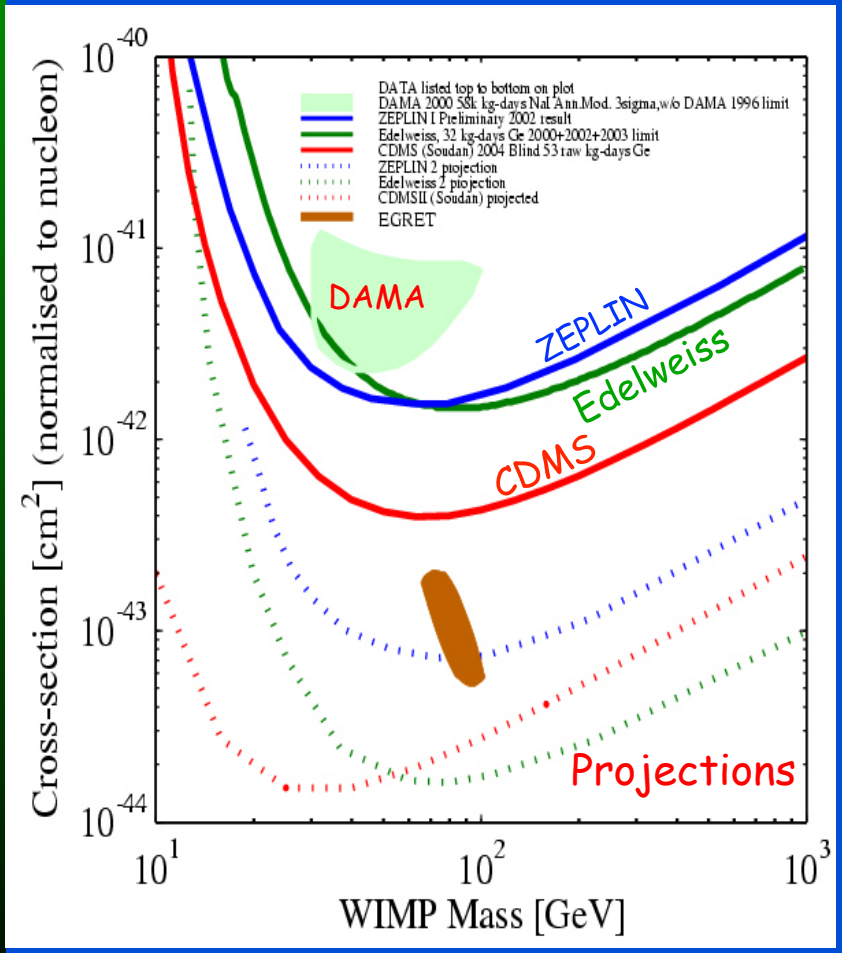


LSP largely Bino ➔ DM may be supersymmetric partner of CMB

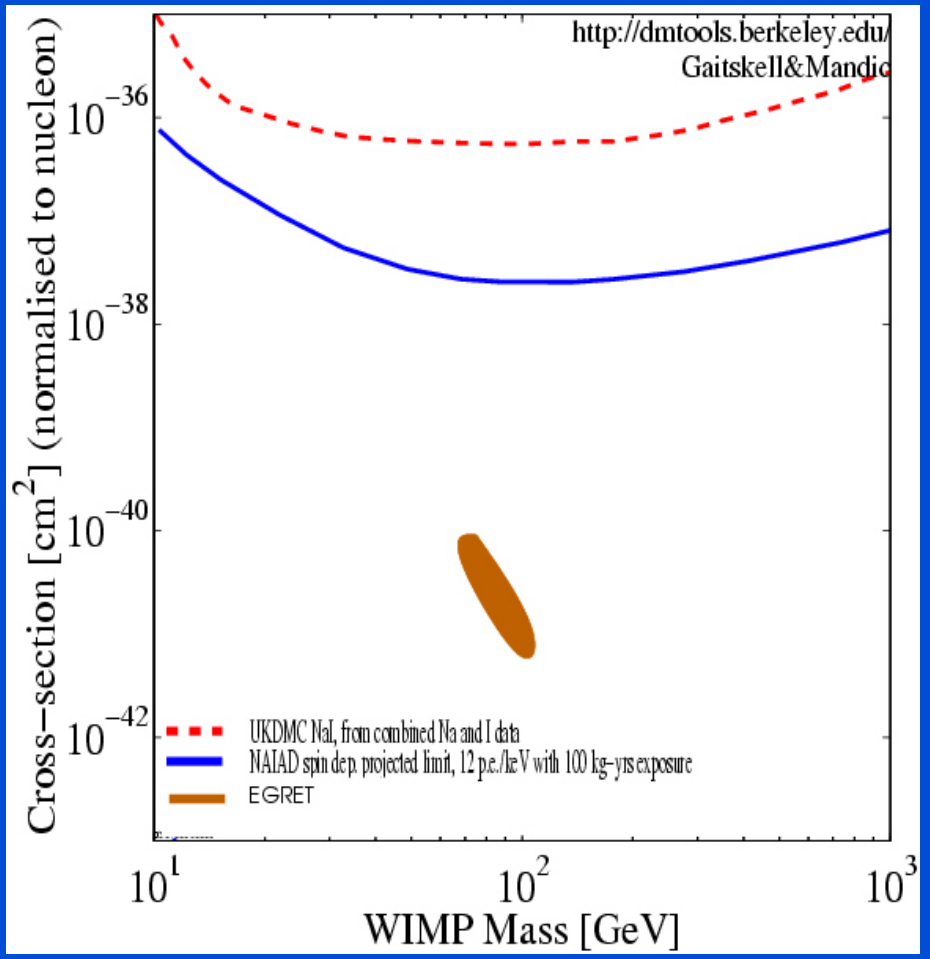
Charginos, neutralinos and gluinos light

Comparison with direct DM Searches

Spin-independent



Spin-dependent



Predictions from EGRET data assuming Supersymmetry

Summary

EGRET excess shows all key features from DM annihilation:

Excess has same shape in all sky directions: everywhere it is perfectly (only?) explainable with superposition of background AND mono-energetic quarks of 50-100 GeV
Results in perfect agreement with SUPERSYMMETRY

Excess follows expectations from galaxy formation:
$1/r^2$ profile with substructure,
visible matter/DM ≈ 0.02

Excess connected to MASS, since it can explain peculiar shape of rotation curve

These combined features provide FIRST (>10σ) EVIDENCE that DM is not so dark and follow ALL DMA expectations imagined so

Conventional models CANNOT explain above points SIMULTANEOUSLY, especially spectrum of gamma rays in all directions,
shape of rotation curve, stability of ring of stars at 14 kpc,..

Summary of summary

EGRET galactic gamma ray data provides intriguing hint that
- since WIMP has properties of a spin ½ photon -

DM is the Supersymmetric Partner of the CMB