

«..Часы трудов свободно
вдохновленных..»

А.Пушкин

DARK MATTER PROFILE OF OUR GALAXY IN SUSY MODEL

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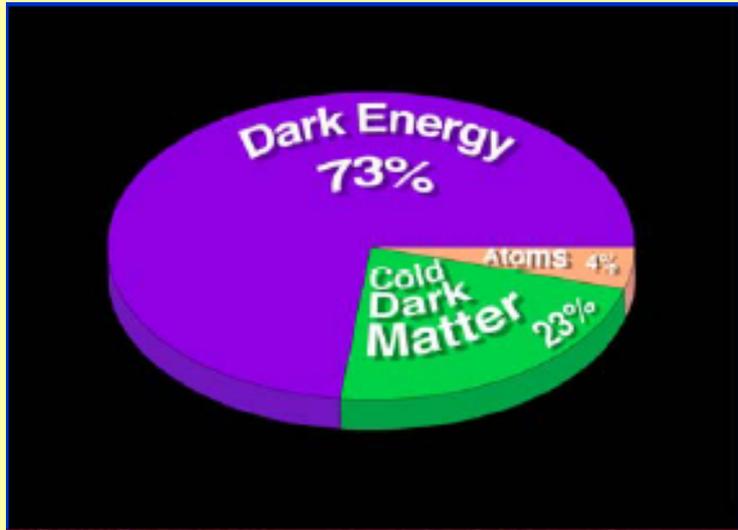
Outline



- Dark Matter in the Universe
- SUSY contribution to the DM
- DM Halo Profile
- Gamma-Ray Fluxes
- Positrons and Antiprotons
- Conclusions



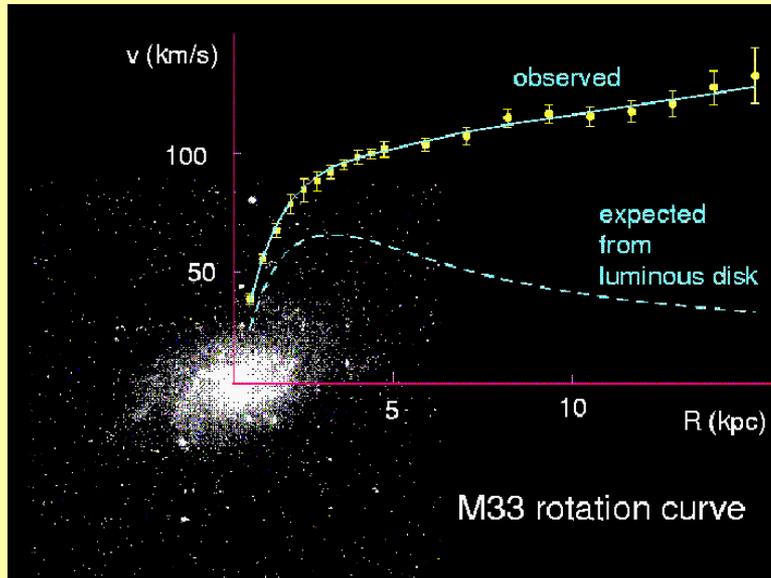
MATTER AND ENERGY CONTENT OF THE UNIVERSE



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

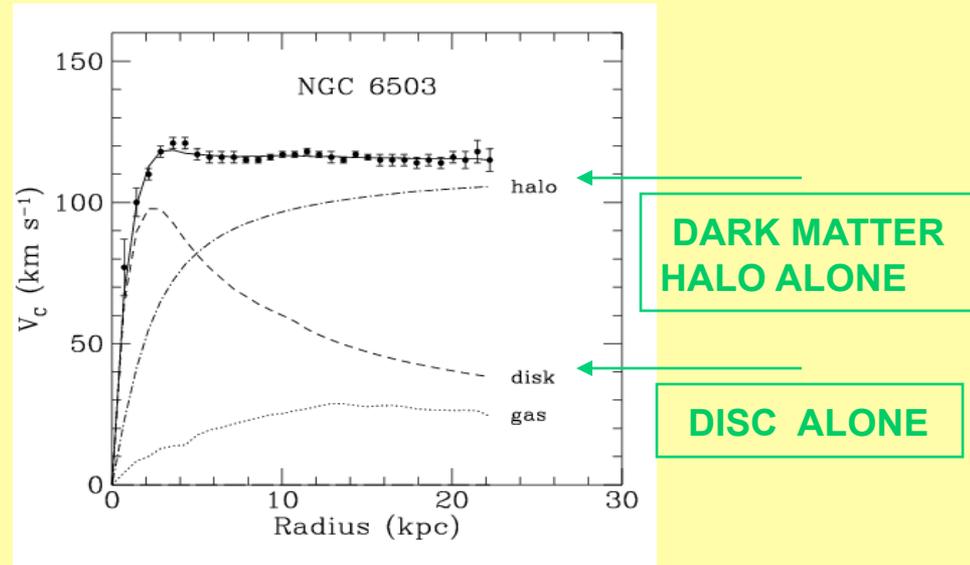
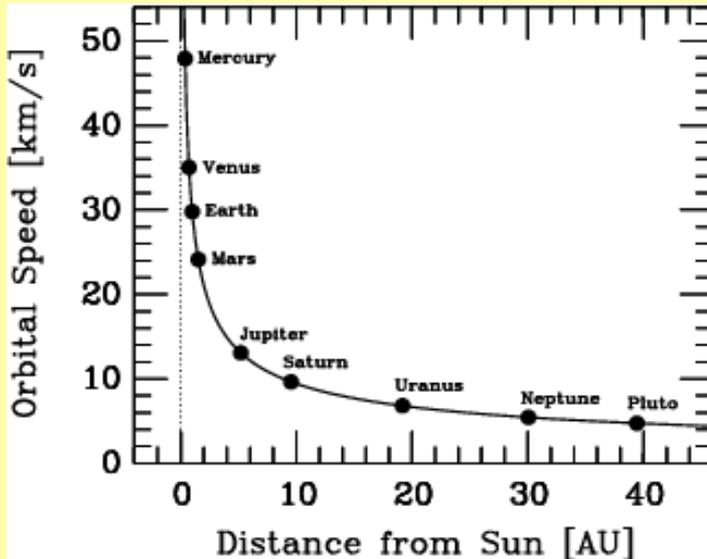


THE FLAT ROTATION CURVES OF SPIRAL GALAXIES PROVIDE THE MOST DIRECT EVIDENCE FOR THE EXISTENCE OF LARGE AMOUNT OF THE DARK MATTER.

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

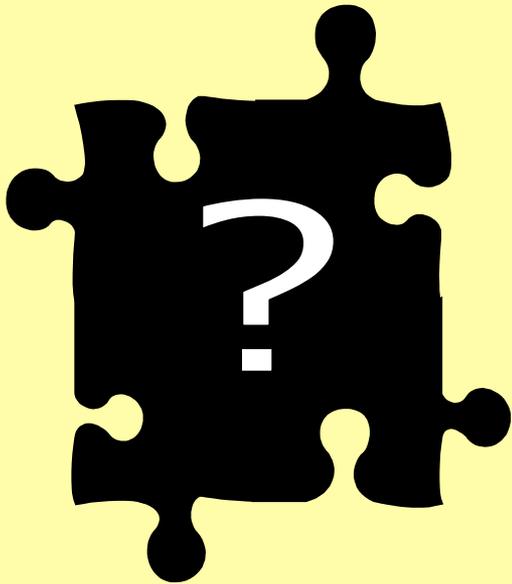


ROTATION CURVES IN SOLAR SYSTEM AND OF THE GALAXIES

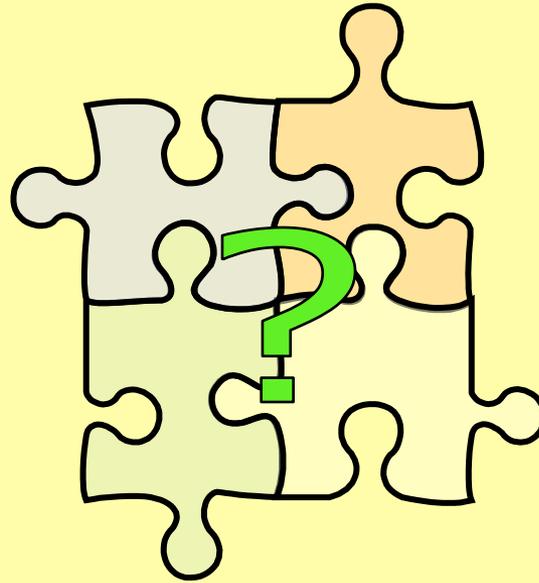


- NOWDAYS, THOUSANDS OF GALACTIC ROTATION CURVES ARE KNOWN, AND ALL SUGGEST THE EXISTENCE OF ABOUT TEN TIMES MORE MASS IN THE HALOS THAN IN THE STARS OF THE DISC
- THE ROTATION CURVE OF THE MILKY WAY HAS BEEN MEASURED AND CONFIRMS THE USUAL PICTURE

WHAT IS THIS MATTER ?



DARK



TRANSPARENT



INVISIBLE

What is it made of ?

PARTICLE CONTENT OF THE MSSM

Superfield	Bosons	Fermions	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$	
<i>Gauge</i>						
G^a	gluon g^a	gluino \tilde{g}^a	8	0	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	
<i>Matter</i>						
L_i	sleptons	$\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	$L_i = (\nu, e)_L$	1	2	-1
E_i			$E_i = e_R$	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			$U_i = u_R$	3^*	1	-4/3
D_i			$D_i = d_R$	3^*	1	2/3
<i>Higgs</i>						
H_1	H_1	higgsinos $\left\{ \begin{array}{l} \tilde{H}_1 \\ \tilde{H}_2 \end{array} \right.$	1	2	-1	
H_2	H_2		1	2	1	

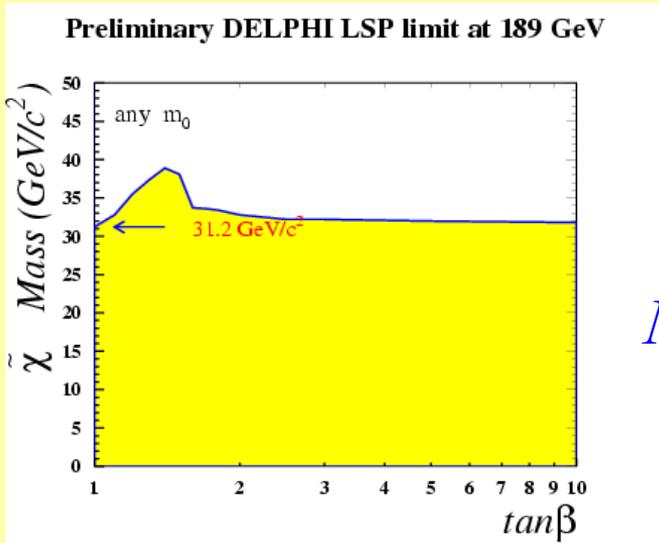
SUSY associates known bosons with new fermions
and known fermions with new bosons

SUSY DARK MATTER

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

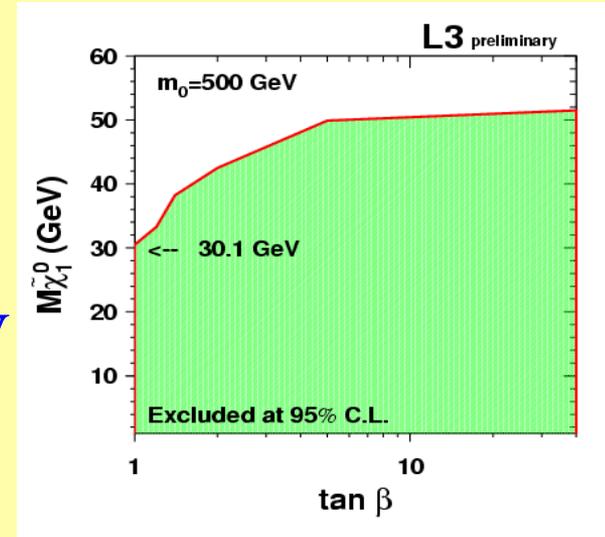
$$\tilde{\chi}^0 = N_1 \tilde{\gamma} + N_2 \tilde{z} + N_3 \tilde{H}_1^0 + N_4 \tilde{H}_2^0$$

photino
zino
higgsino
higgsino



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

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



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

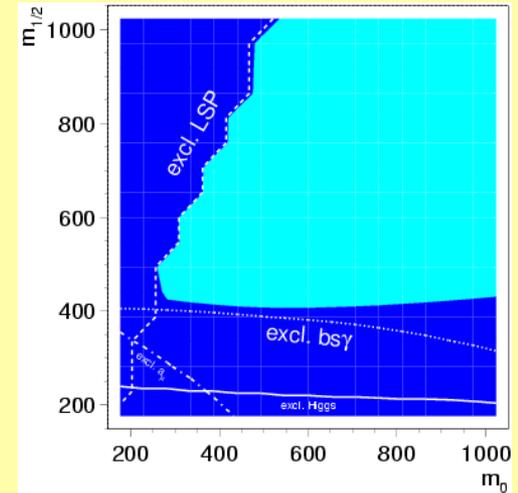
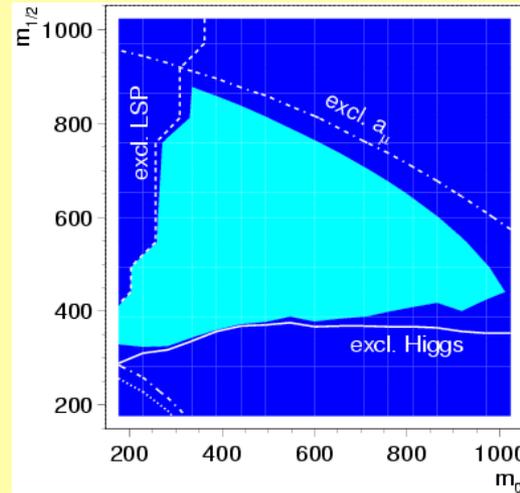
ALLOWED REGIONS OF PARAMETER SPACE

- $\tan \beta > 4$

From the Higgs searches

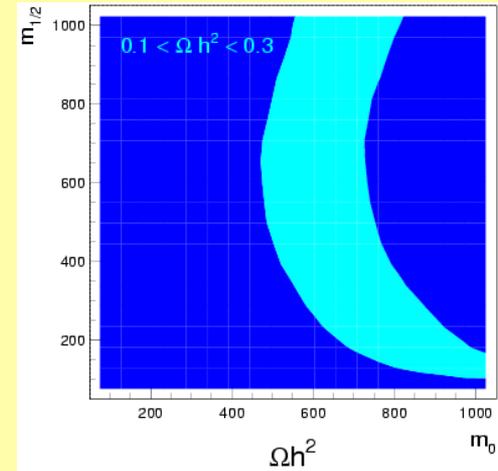
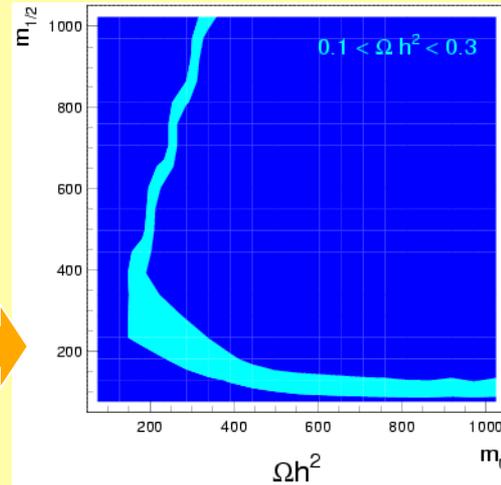
- $\mu > 0$

From a_μ measurement



In allowed region one fulfills all the constraints simultaneously and has the suitable amount of the dark matter

Fit to all constraints



BEFORE WMAP

$\tan \beta = 35$

Fit to Dark Matter constraint

$\tan \beta = 50$

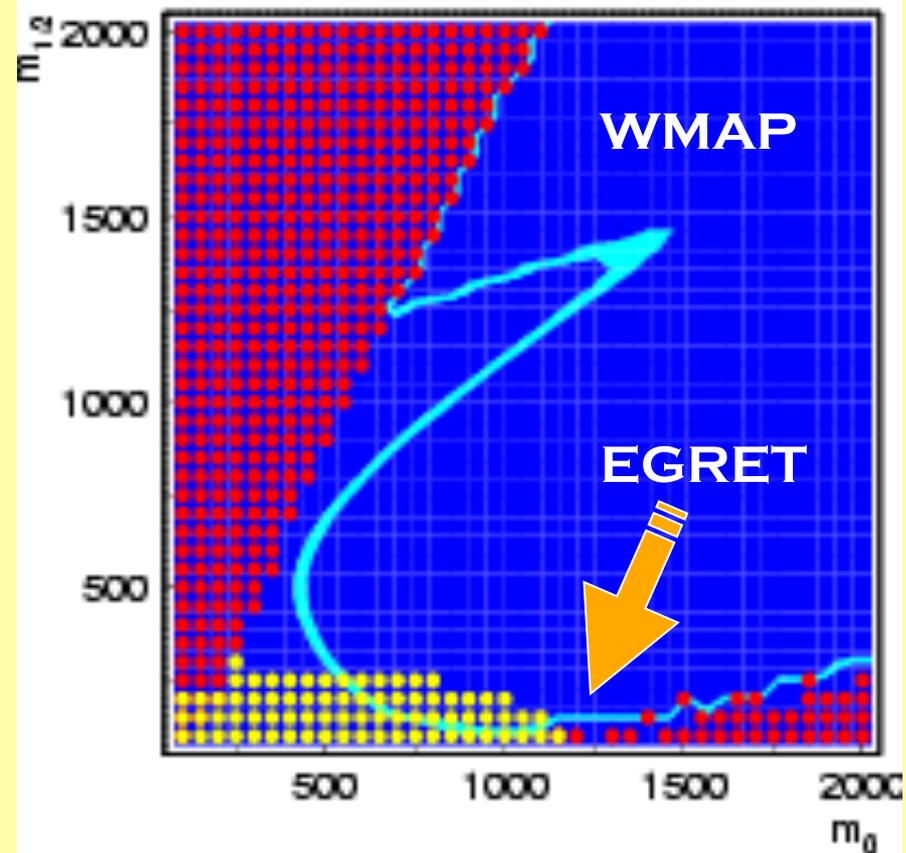
ALLOWED REGIONS OF PARAMETER SPACE

AFTWER WMAP

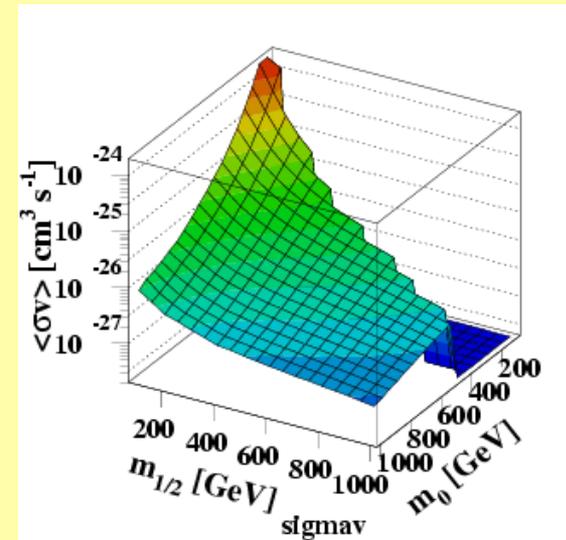
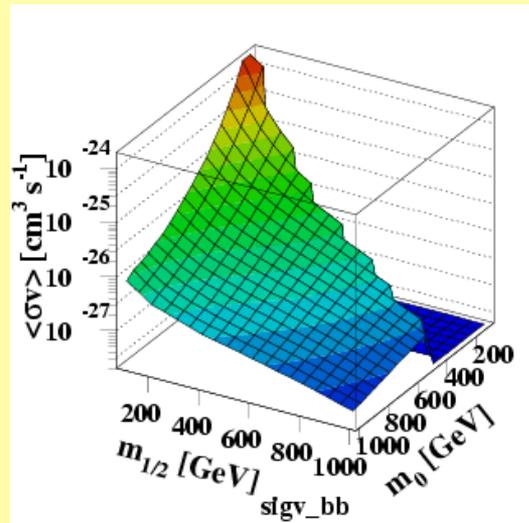
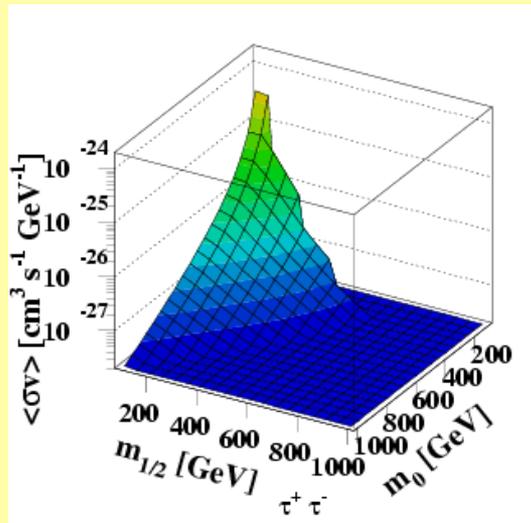
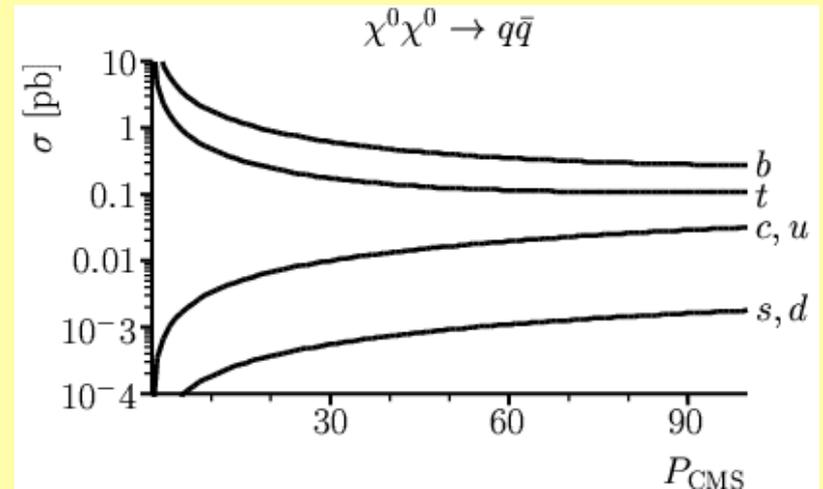
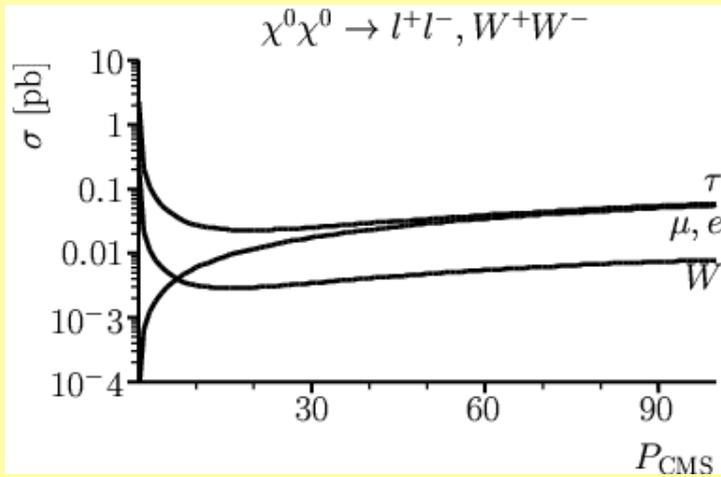
Fit to Dark Matter constraint

$\tan \beta = 50$

In allowed region
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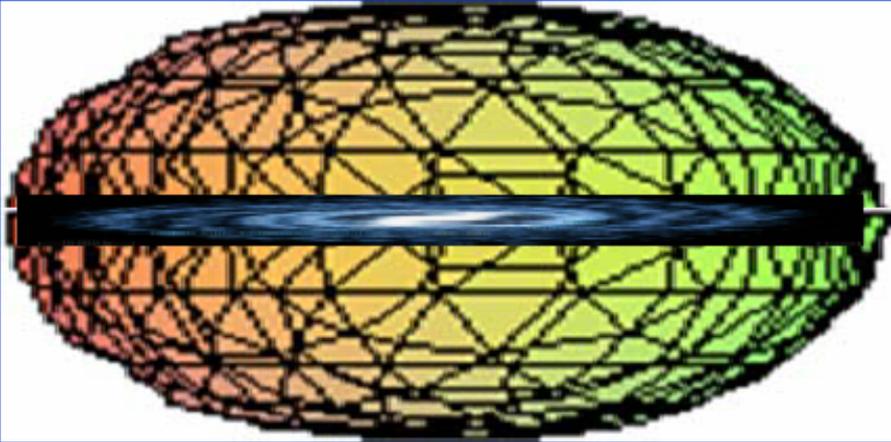


NEUTRALINO ANNIHILATION X-SECTIONS



HALO PARAMETERS

Semi axis in z-direction=
0.4 semi axis in x,y-direction



Contour of constant DM density
Halo parameters in NFW profile
fitted by requiring minimal
difference between boostfactors
of various regions.

$$\rho_{NEW} = \frac{\rho_0}{\left(\frac{r}{a}\right)^\gamma \left[1 + \left(\frac{r}{a}\right)^\alpha\right]^{(\beta-\gamma)/\alpha}}$$

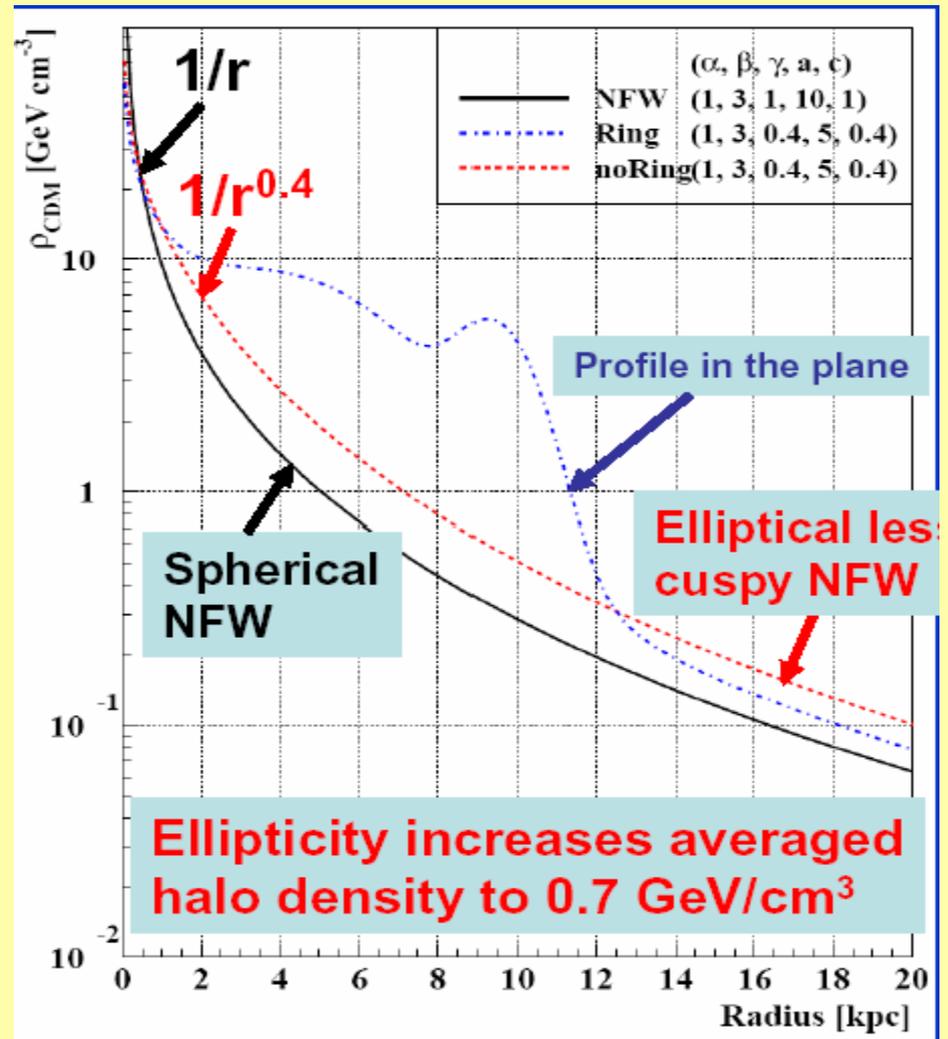
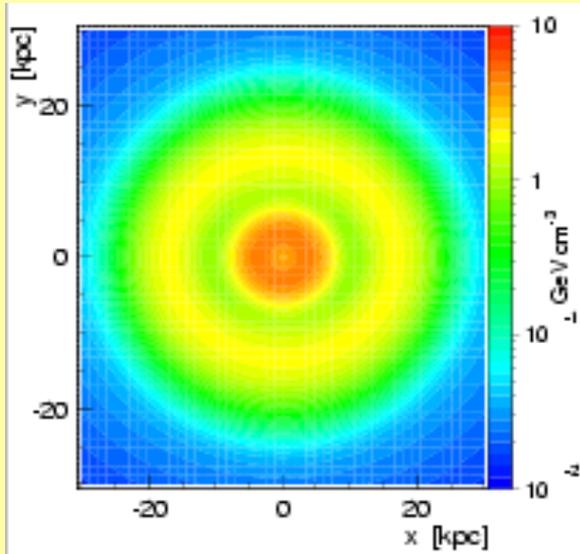
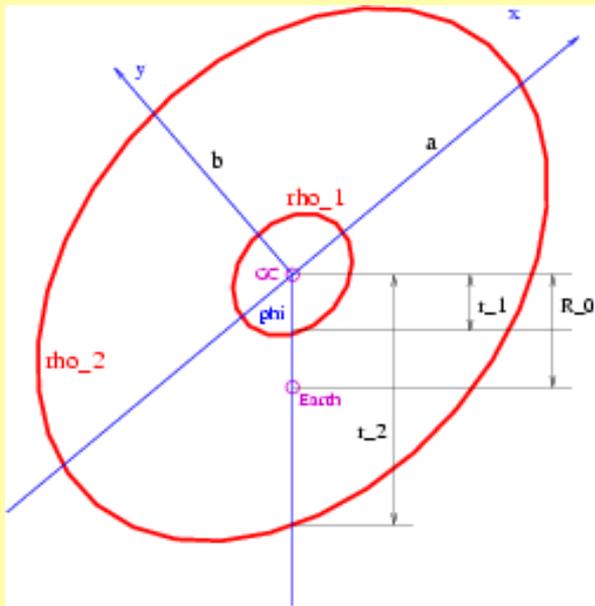
(3,1,1) CUSPY PROFILE

$$\rho_{NEW} = \frac{\rho_0}{\left(\frac{r}{a}\right) \left[1 + \left(\frac{r}{a}\right)^2\right]^2}$$

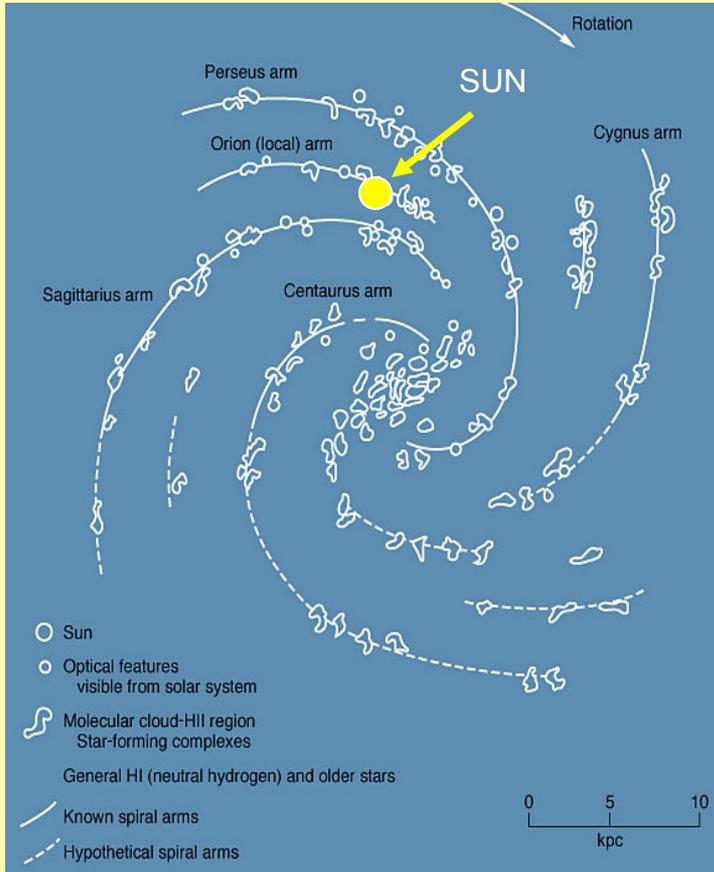
(2,2,0) NON-CUSPY PROFILE

$$\rho_{NEW} = \frac{\rho_0}{\left[1 + \left(\frac{r}{a}\right)^2\right]^2}$$

HALO PARAMETERS



ROTATION CURVE FOR THE MILKY WAY

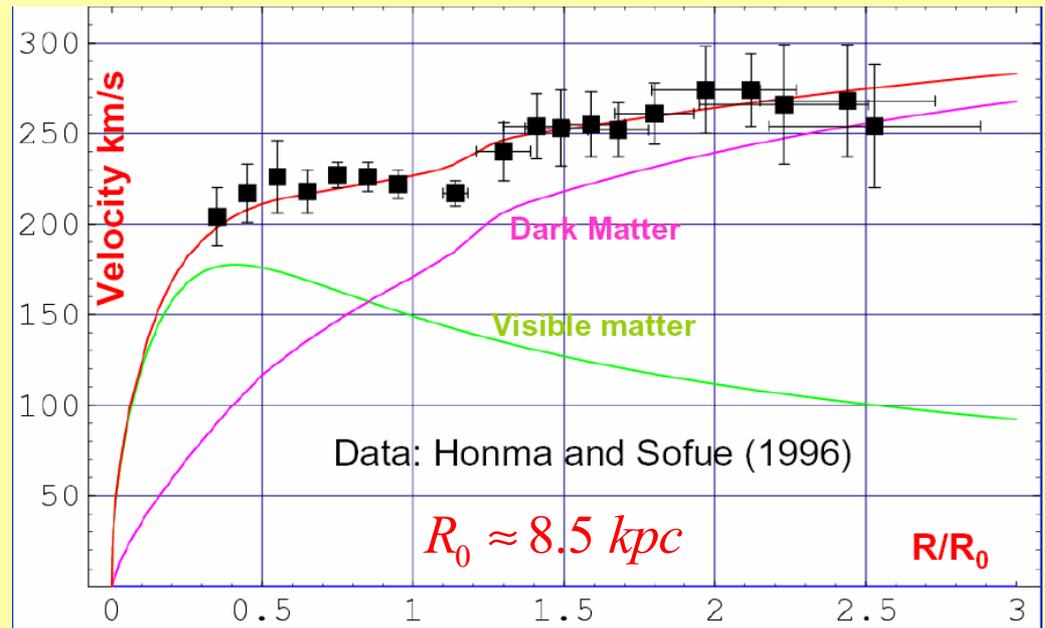


$$v_{total} = \sqrt{v_{disk}^2 + v_{gas}^2 + v_{DM}^2}$$

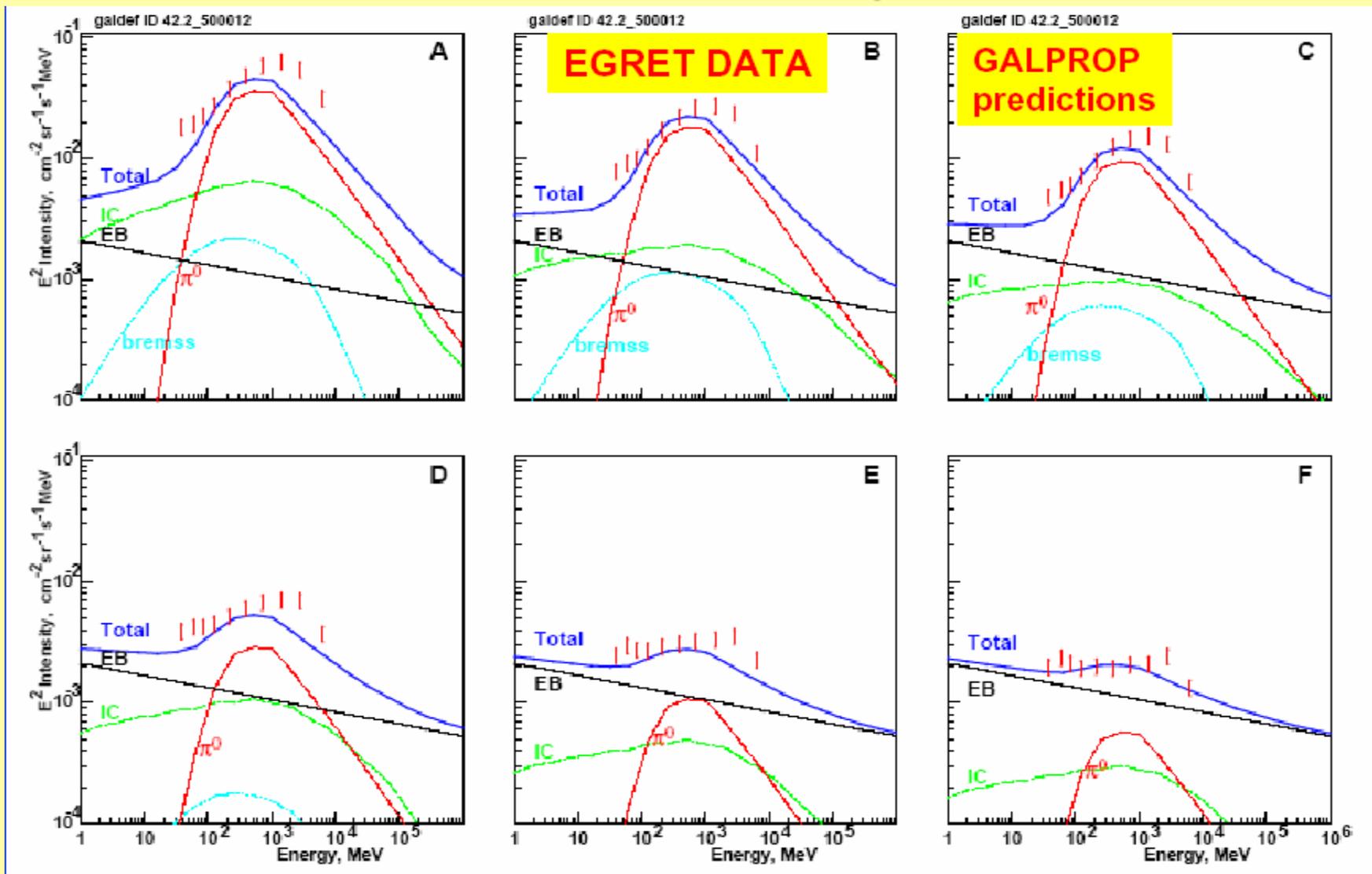
$$v_{disk}(r) = \frac{v_{d0} \sqrt{r/R_d}}{\sqrt{1 + (r/R_d)^2}} \quad v_{gas} \approx const \approx 0$$

$$v_{DM} = \sqrt{G_N Mass(r) / r}$$

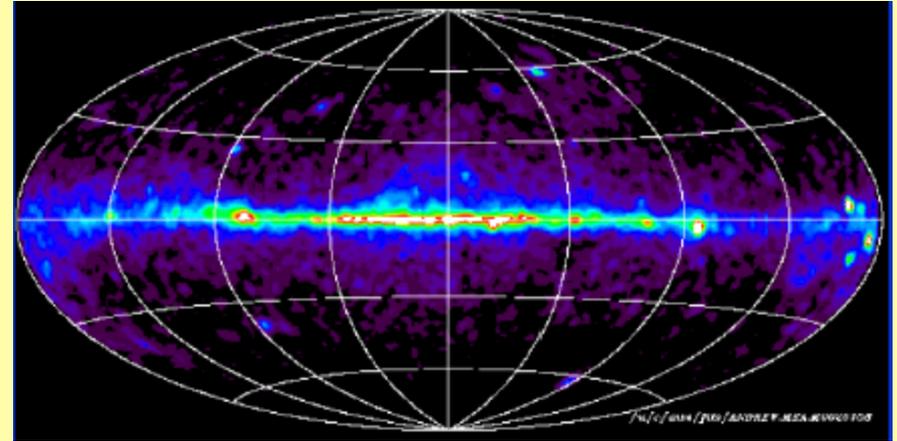
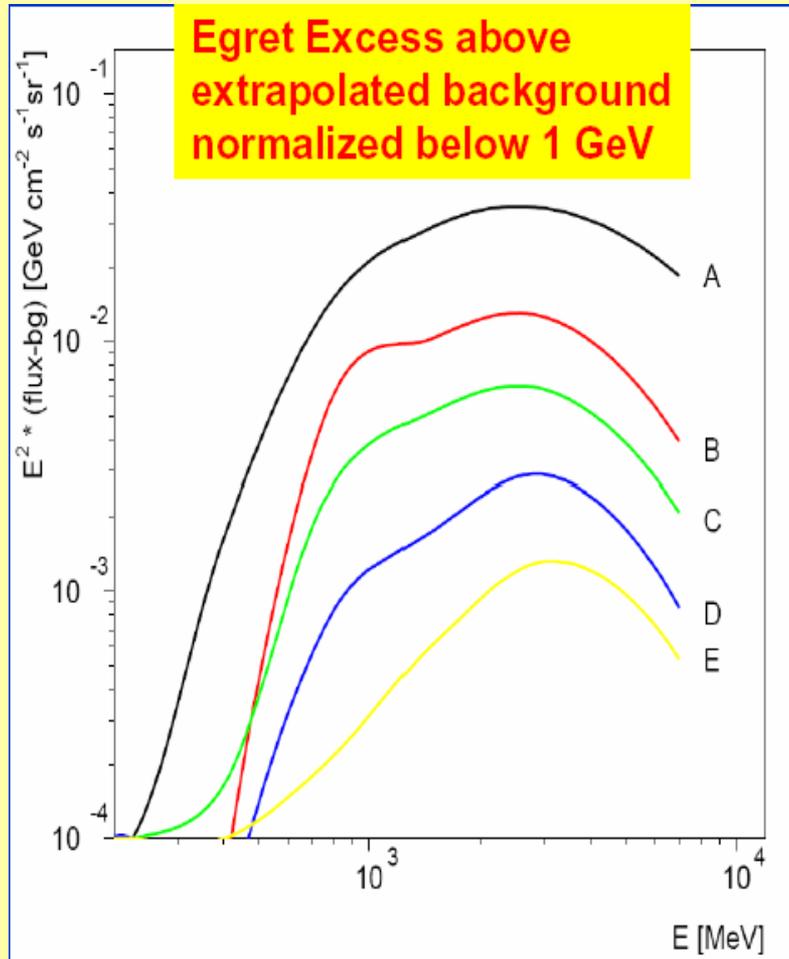
$$Mass(r) = \int_0^r d^3r \rho(r) \quad \rho = \rho_{NFW} + \rho_{arms}$$



Excess of Diffuse Gamma Rays above 1 GeV



Diffuse Gamma Rays in EGRET Energy Range



- A: inner Galactic plane ($\pm 30^\circ$)**
- B: Galactic plane avoiding inner Galaxy ($30-330^\circ$)**
- C: Outer Galaxy ($90-270^\circ$)**
- D: low Latitude ($10^\circ-20^\circ$)**
- E: intermediate Latitude**
- F: galactic poles ($60^\circ-90^\circ$)**

Excess same shape in all regions implying same source everywhere in galaxy

GAMMA RAY FLUX FROM THE DM

$$Flux_{\gamma}(\theta, \phi) = \frac{N_{\gamma} \sigma v}{4\pi m_{\chi}^2} \int_0^{\infty} dl \rho_{\chi}^2(l, \theta, \phi) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

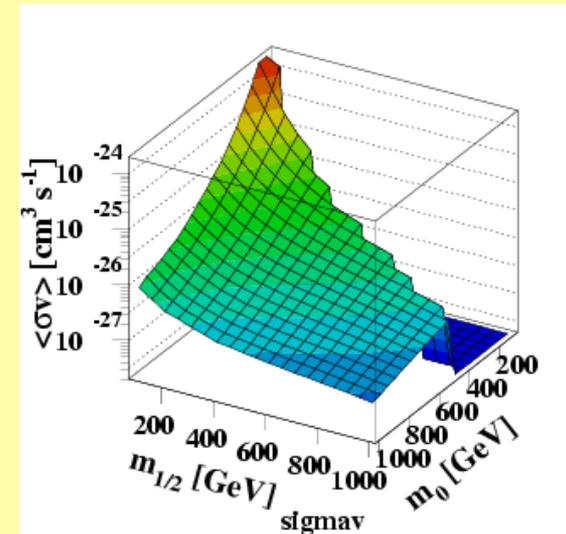
Galactic longitude

Galactic latitude

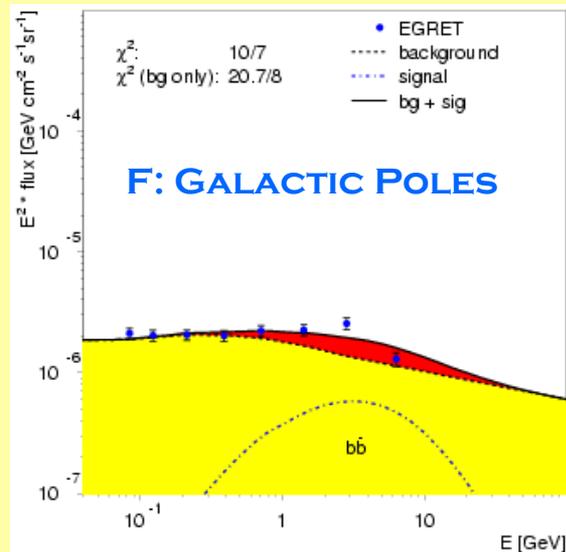
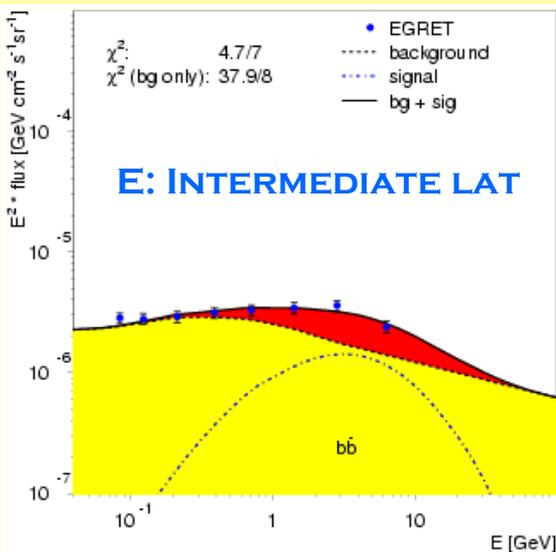
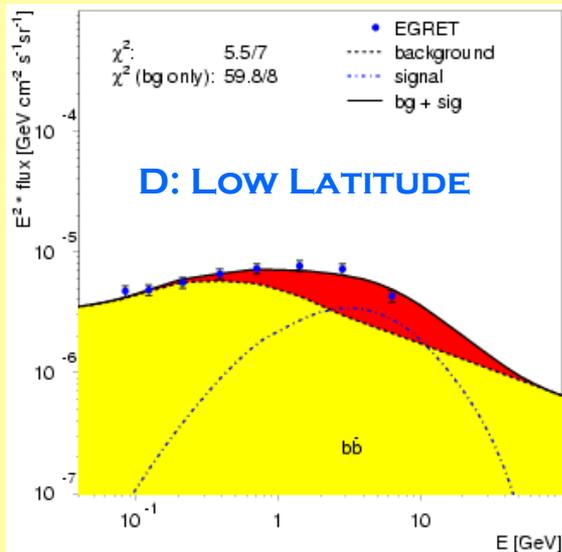
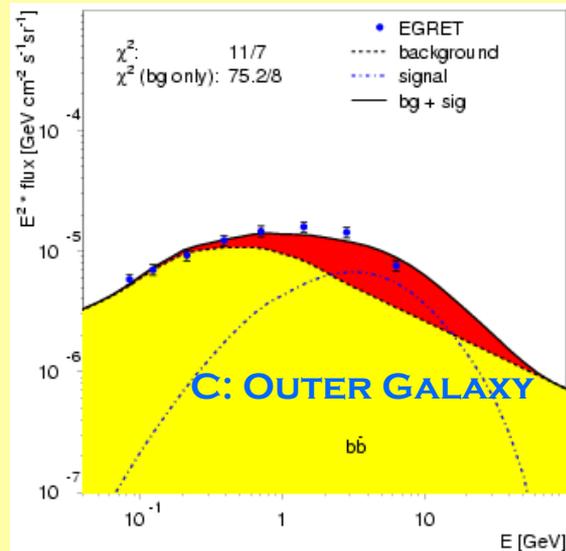
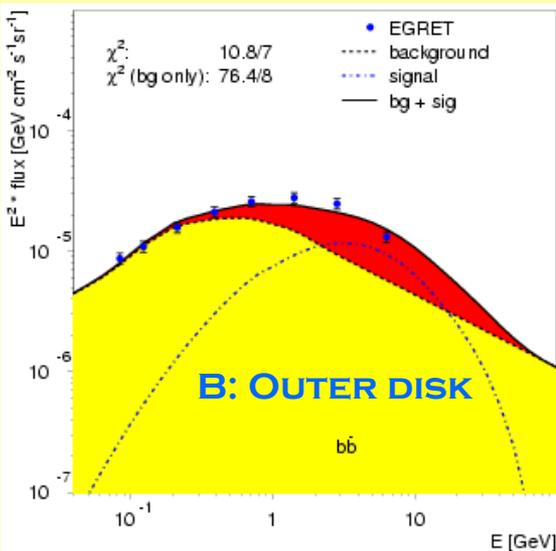
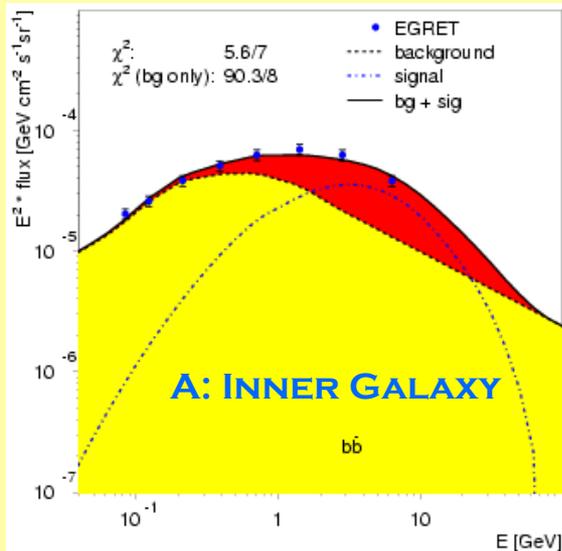
$$N_{\gamma} = 4, m_{\chi} : 60 - 90 \text{ GeV}$$

THERMALLY AVERAGED CROSS-SECTIONS

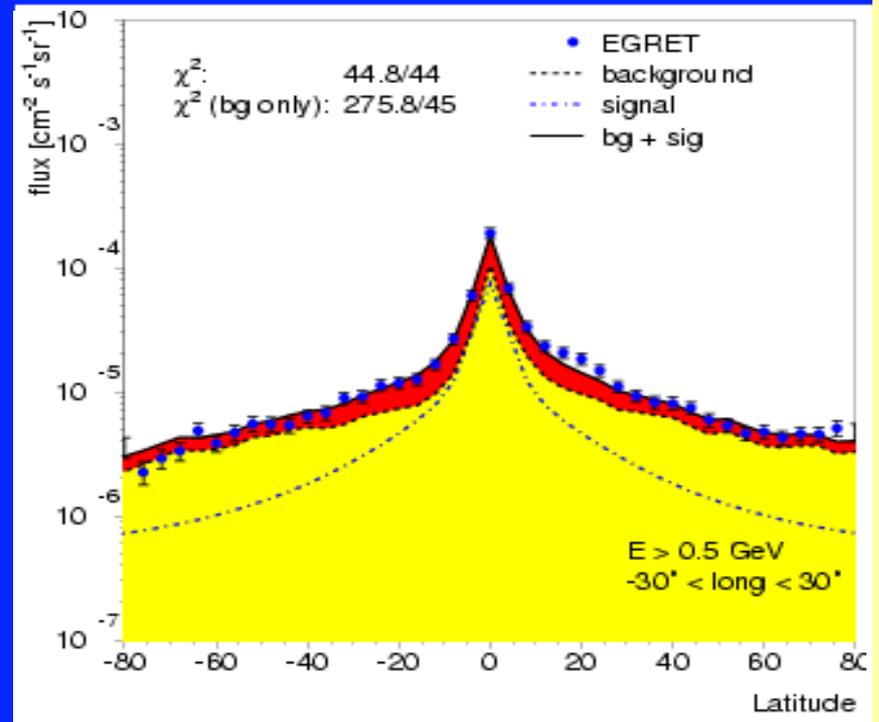
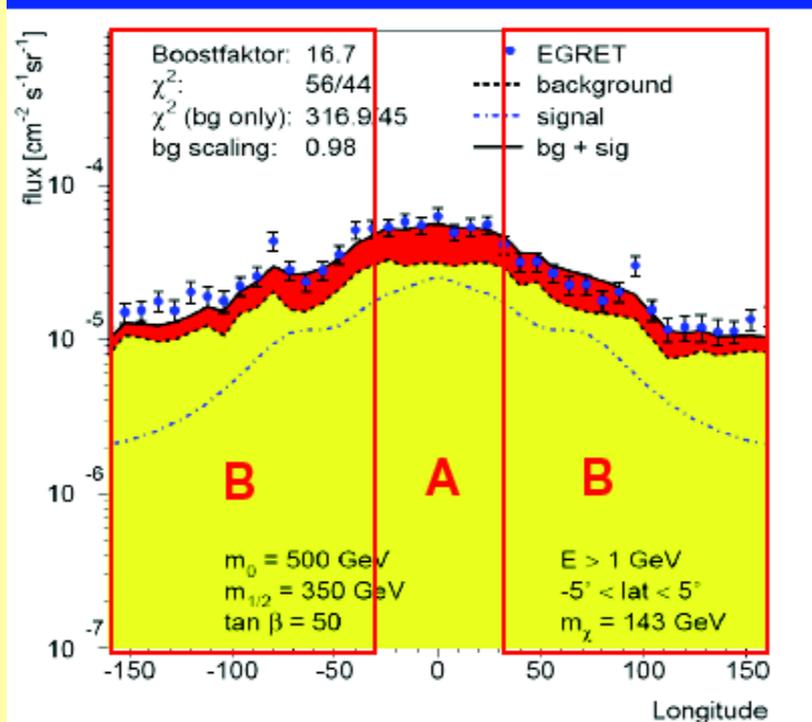
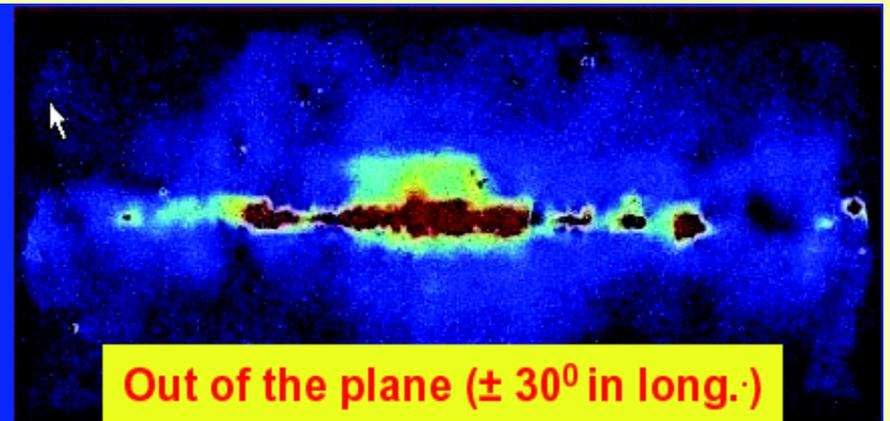
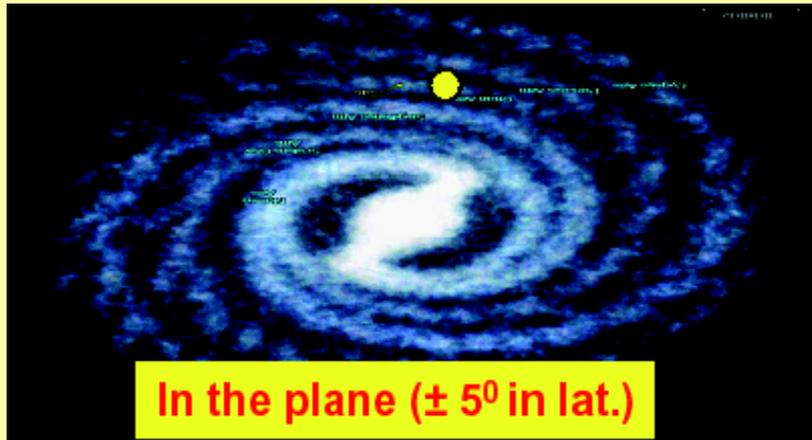
$$\langle \sigma v \rangle = \frac{\int_0^{\infty} dp p^2 4p \sqrt{4p^2 + 4m_{\chi}^2} K_1\left(\frac{\sqrt{4p^2 + 4m_{\chi}^2}}{T}\right) \sigma(p)}{m_{\chi}^4 T [K_2\left(\frac{m}{T}\right)]^2}$$



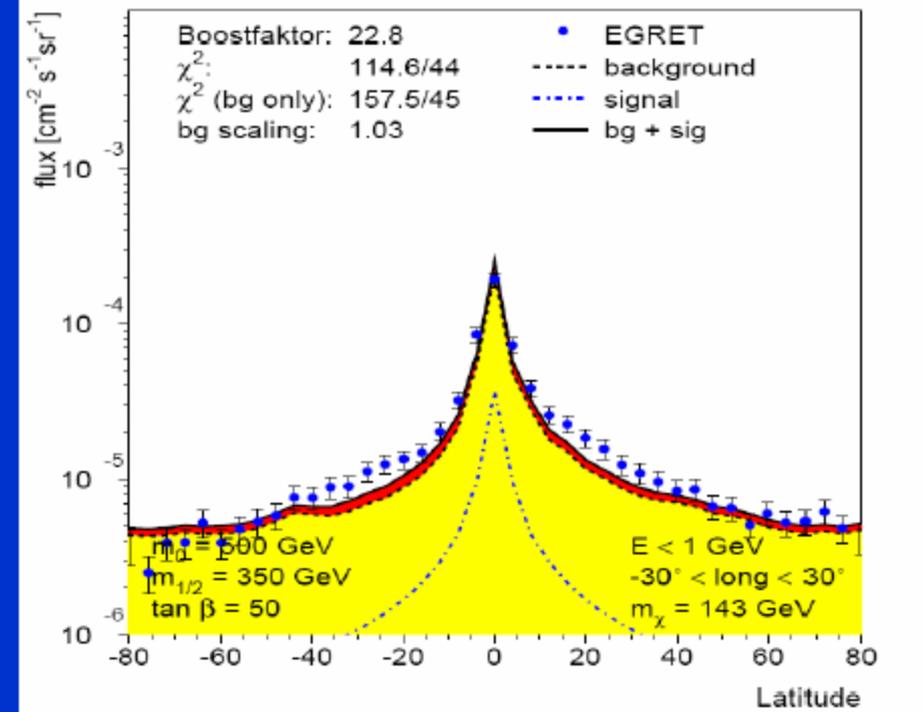
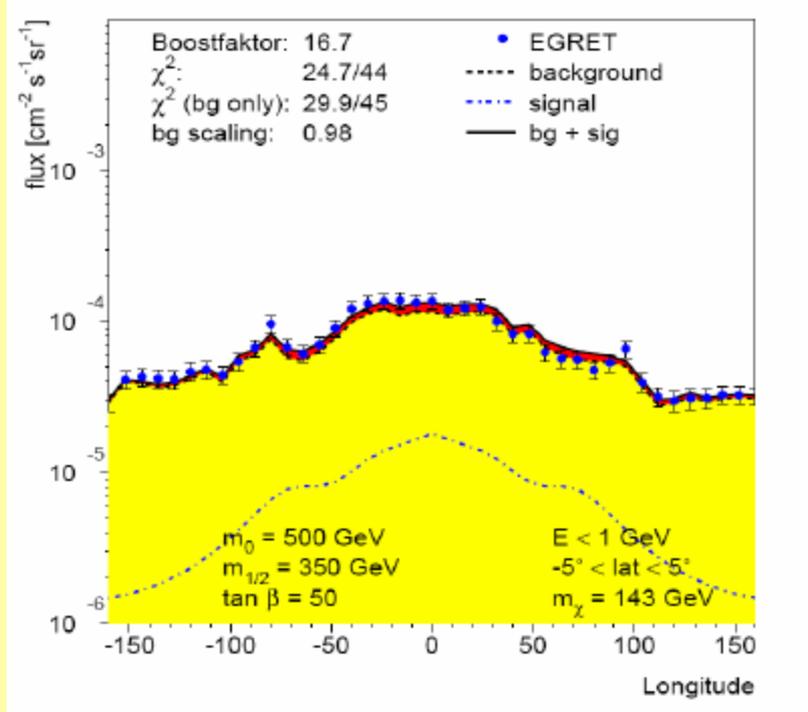
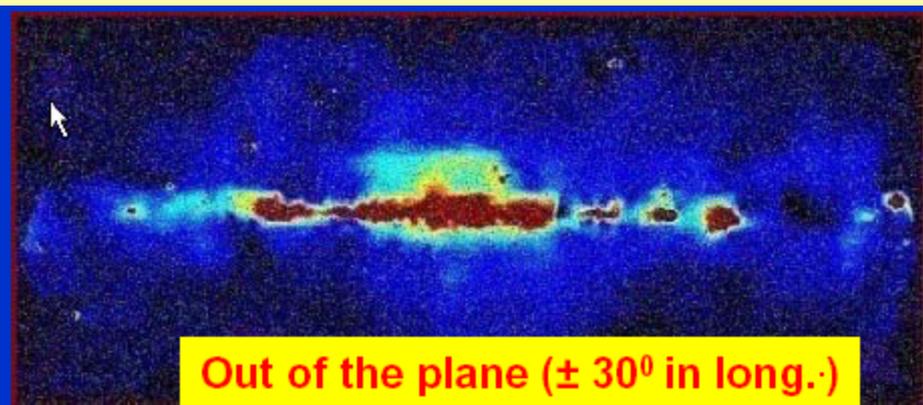
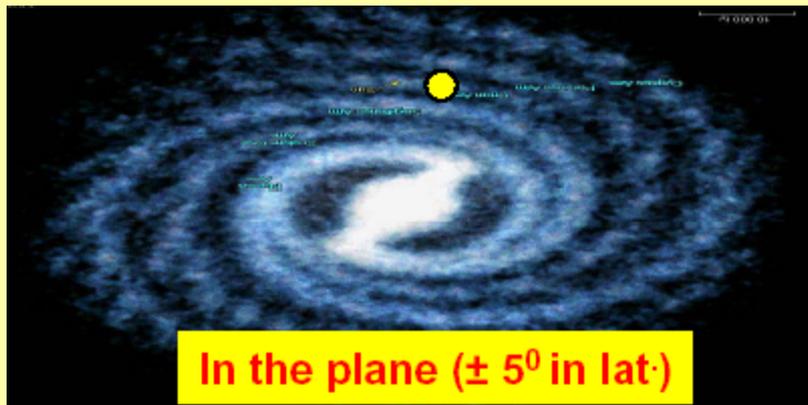
Excess of Gammas versus Energy for various regions



Longitude and Latitude for Gammas ABOVE 1 GeV



Longitude and Latitude for Gammas BELOW 1 GeV

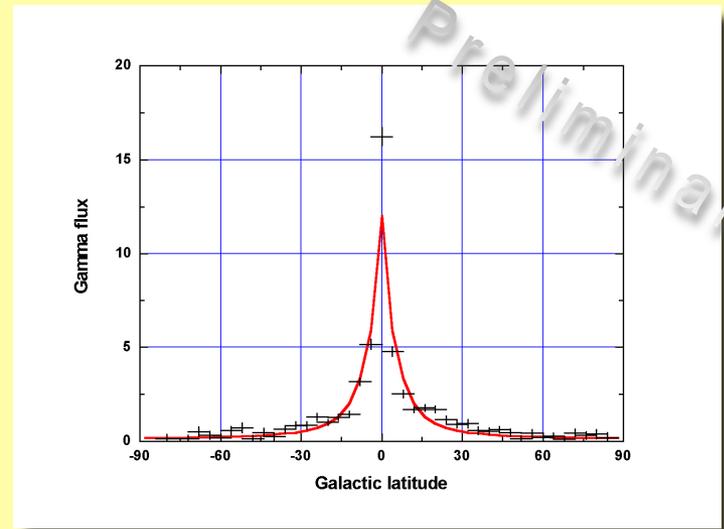
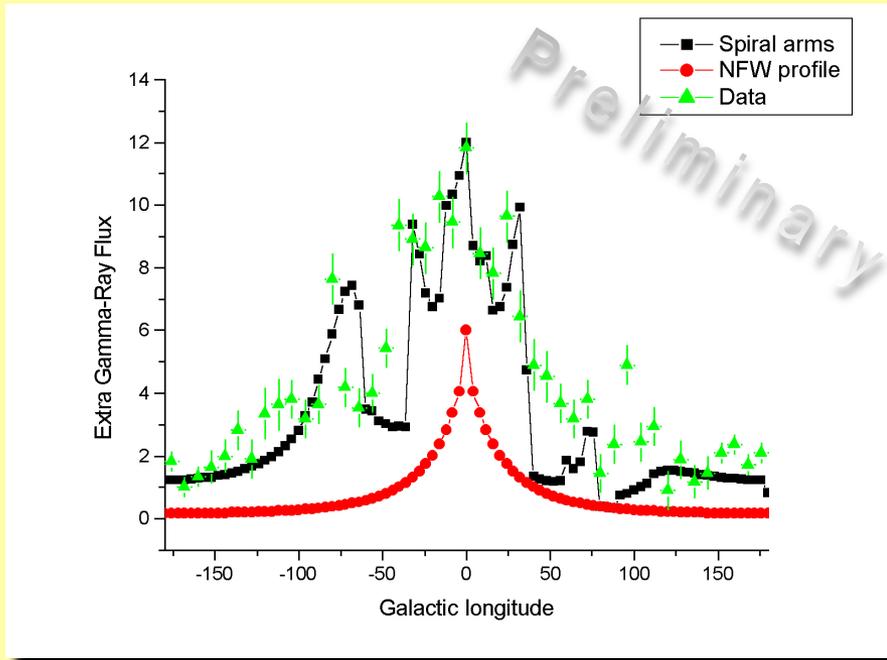


LONGITUDE AND LATITUDE DISTRIBUTION

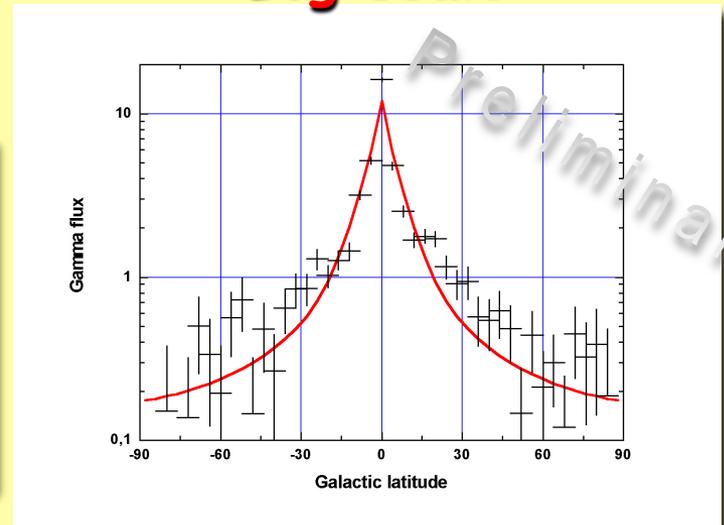
Longitude

SPIRAL ARMS

Latitude

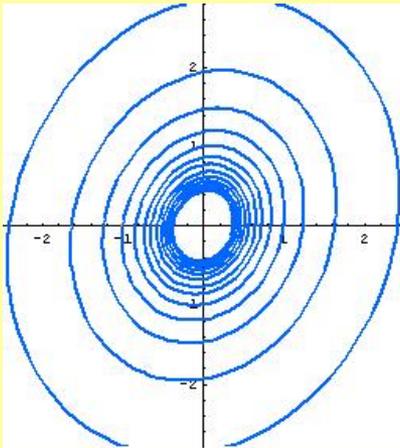


Log scale



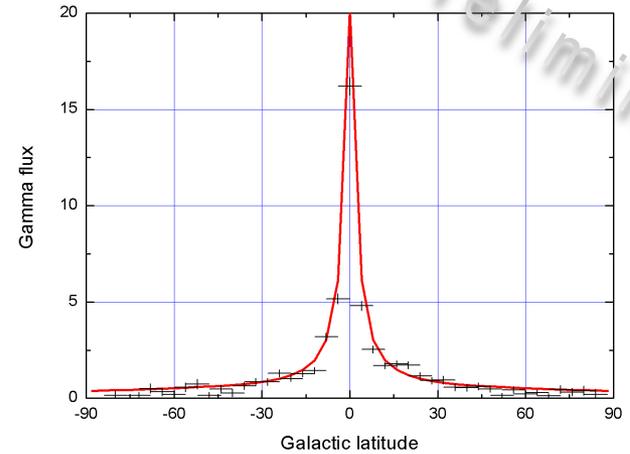
- Peaks in longitude distribution may be fitted by spiral arms contribution
- This indicates that DM is clustered and rotates with visible matter

LONGITUDE AND LATITUDE DISTRIBUTION

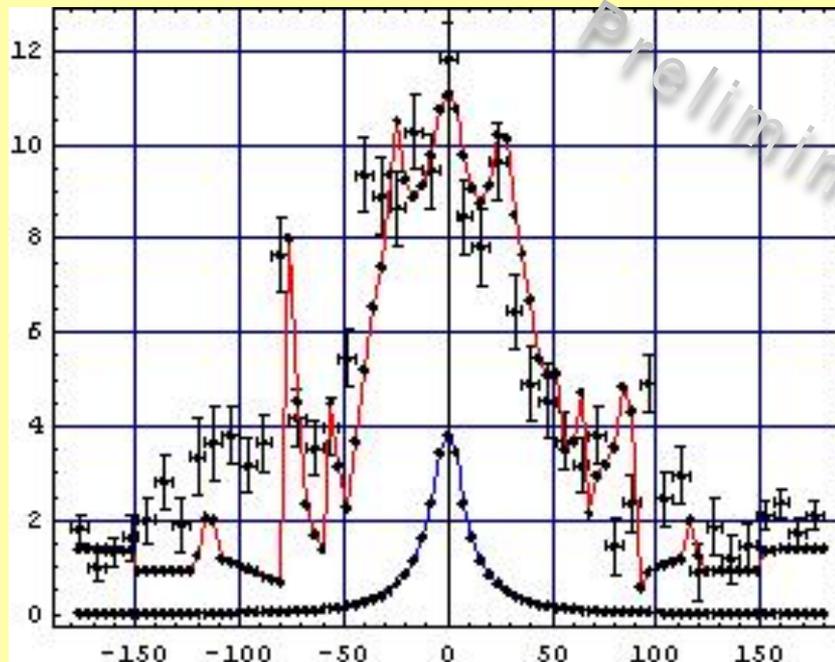


CAUSTIC RINGS

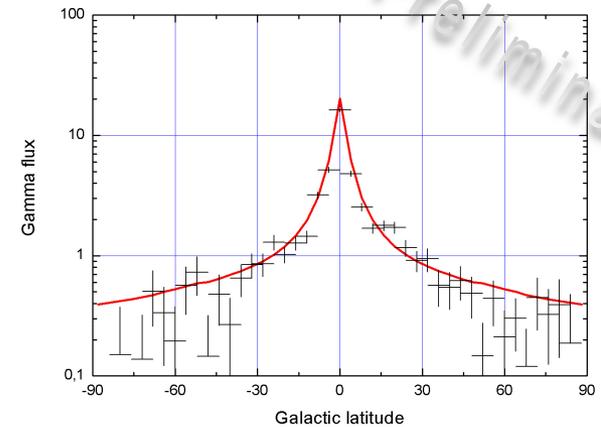
Latitude



Longitude



Log scale



POSITRONS FROM THE DARK MATTER ANNIHILATION

- The Flux

$$\frac{dF}{dE} = \langle \sigma v \rangle \frac{\rho_0^2}{m_\chi^2} \int d\varepsilon G(E, \varepsilon) \sum_i B_i f_i(\varepsilon)$$

neutralino density
thermal averaging
propagator
branching
spectrum

- The propagator

$$G(E, \varepsilon) = 10^{25} [10^{a \log^2 E + b \log E + c} \theta(\varepsilon - E) + 10^{w \log^2 E + x \log E + y} \theta(E - \varepsilon)]$$

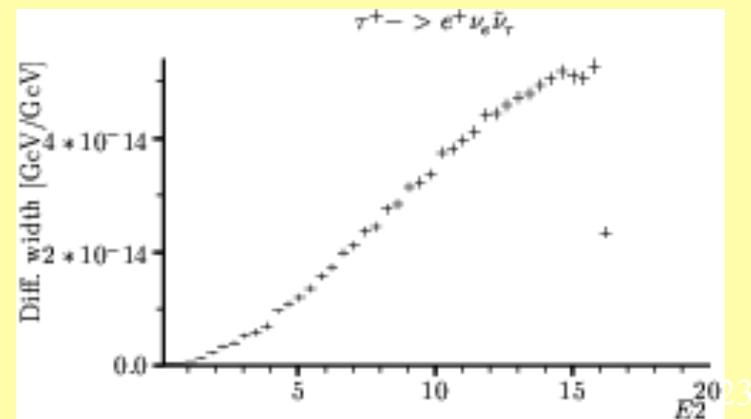
- The Spectrum

Two body decay (boosted)

$$f_W(\varepsilon) = \frac{1}{m_\chi \beta_W} \theta(\varepsilon - \varepsilon_-) \theta(\varepsilon - \varepsilon_+)$$

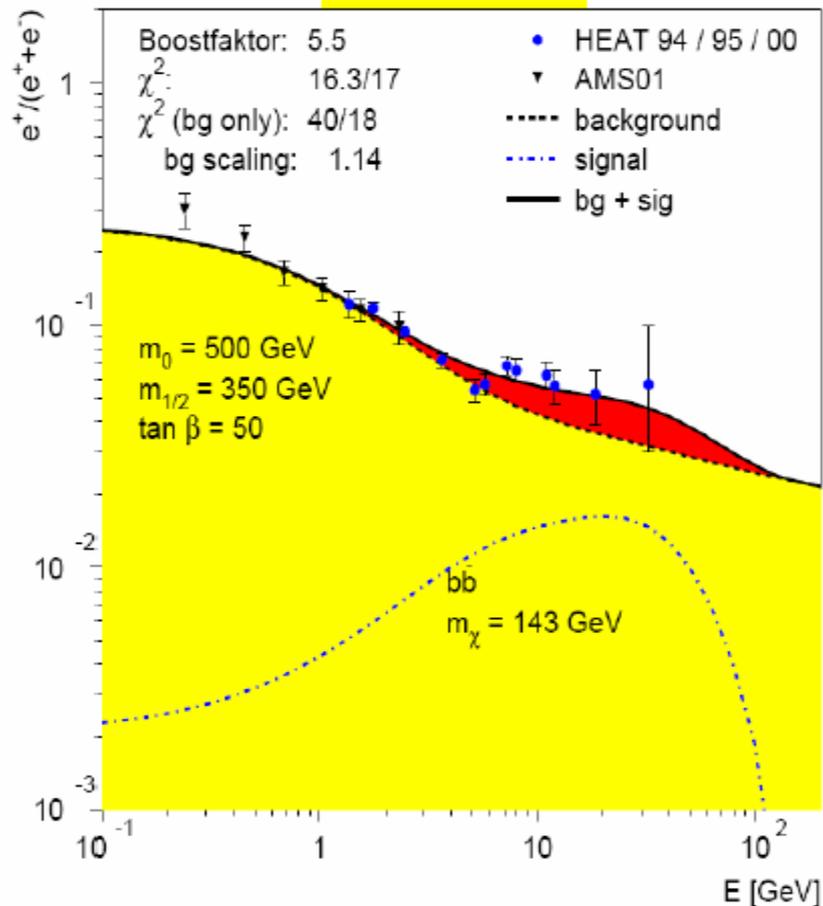
$$\varepsilon_\pm = \frac{1}{2} m_\chi (1 \pm \beta_W), \quad \beta_W \approx \sqrt{1 - \frac{M_W^2}{m_\chi^2}}$$

The τ^+ three body decay (for p=50 GeV)

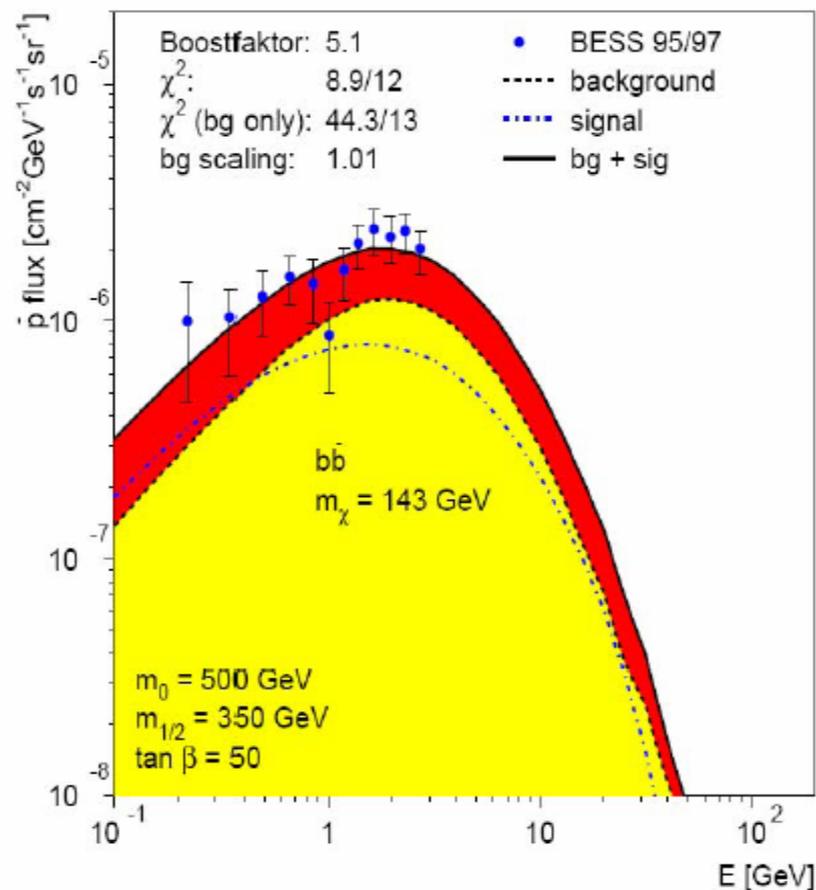


POSITRON FRACTION AND ANTIPROTONS FROM DM ANNIHILATION

Positrons

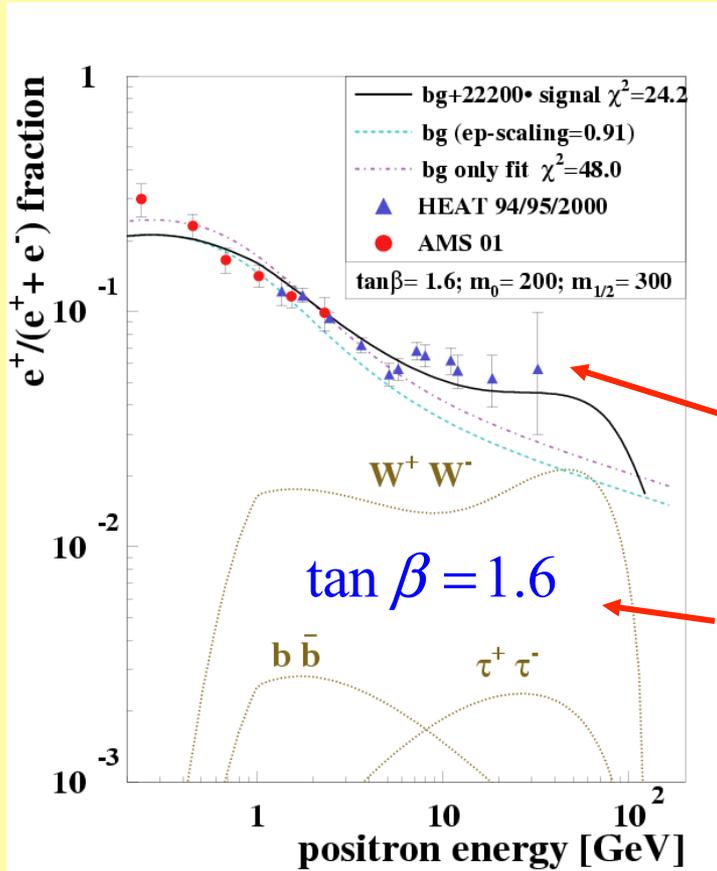


Antiprotons



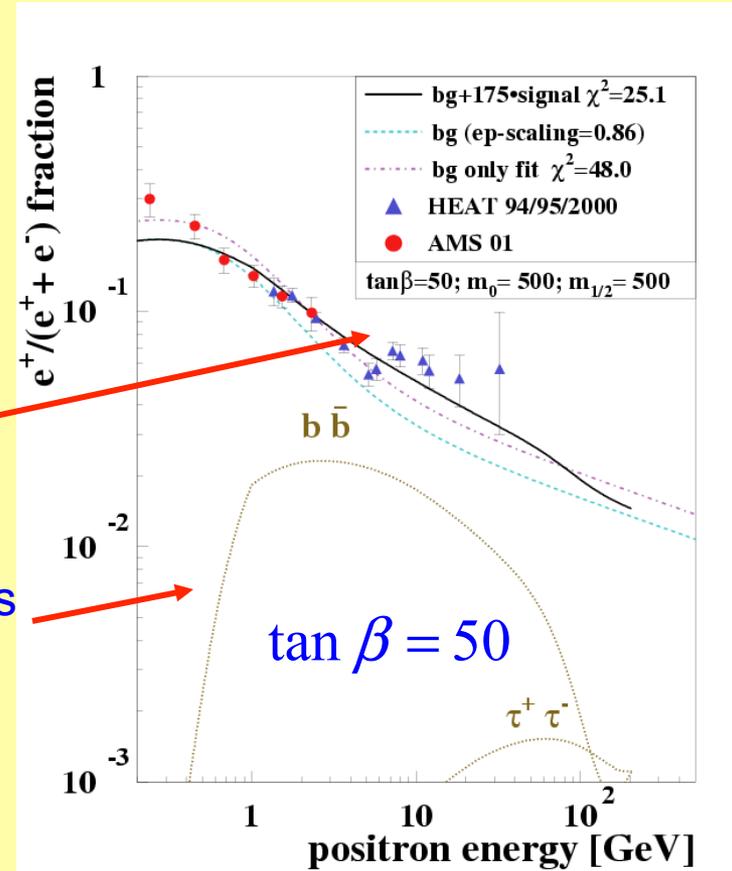
SAME Halo and MSSM parameters as for GAMMAS

POSITRON SPECTRUM AT HIGH ENERGIES



Excess

Extra contributions due to neutralino annihilation

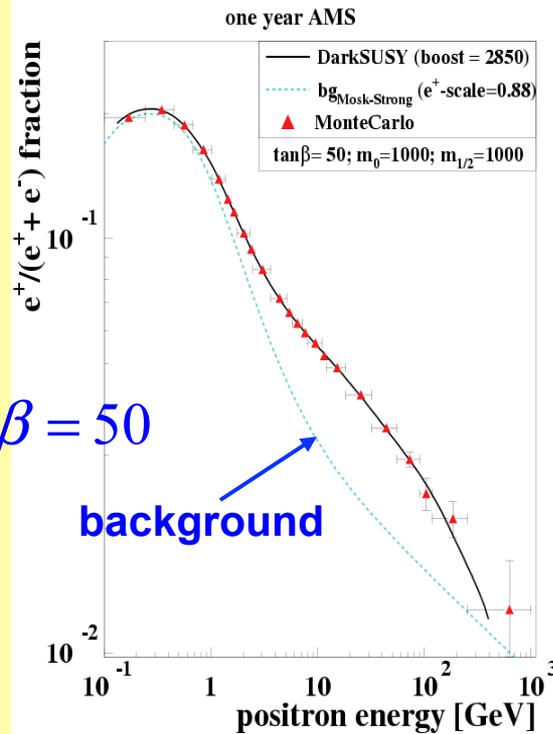
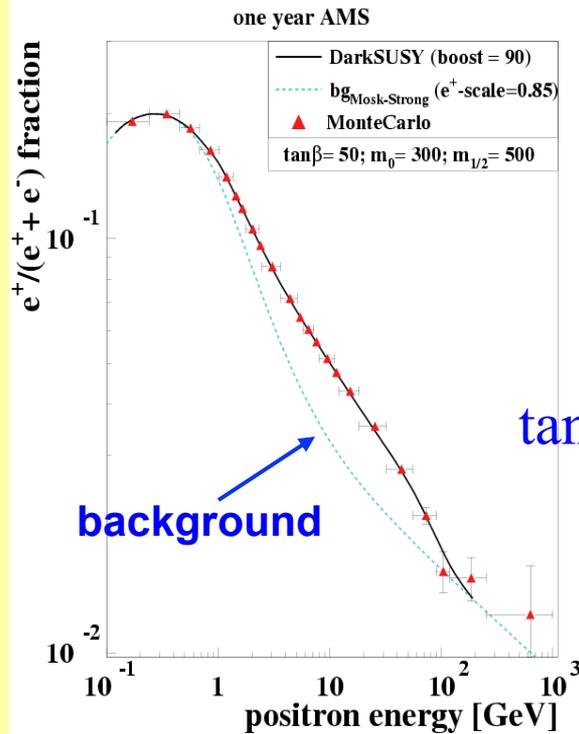


HEAT and AMS-01 balloon experiments show some excess of data at $E > 7$ GeV, which may indicate at extra source of positrons

The dark matter profiles are fitted to the rotation curves

$$\rho_0 : 0.4 \text{ GeV cm}^{-3} = 1 \text{ neutralino per coffee cup}$$

ANTIMATTER SEARCH IN SPACE at ISS: AMS-02



$\tan \beta = 50$

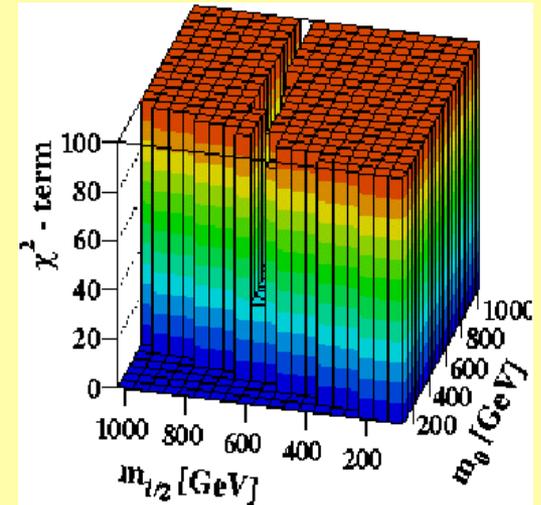
background

background

$m_0 = 300, m_{1/2} = 500$

$m_0 = 1000, m_{1/2} = 1000$

Expected statistics



The χ^2 distribution

- PAMELA – 2004-5 & AMS-02 – 2007

SUMMARY

EGRET data shows excess of gammas above 1 GeV in ALL DIRECTIONS!
SAME spectrum in all regions of sky map strongly suggests COMMON origin.
Excess well described by neutralino annihilation for neutralino mass between 50 and 100 GeV and MSSM parameters compatible with WMAP.

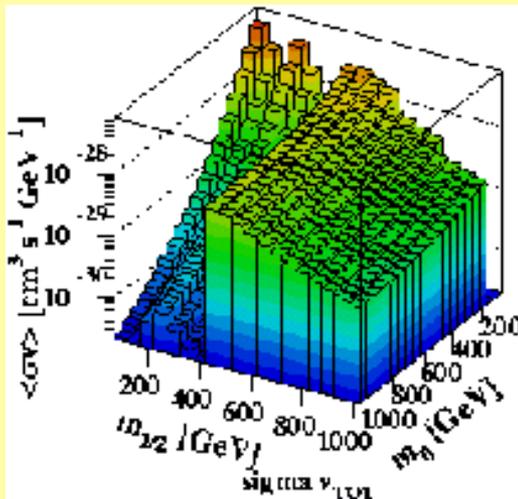
Distribution of DM described by elliptical halo with modified NFW profile (somewhat less cuspy) and smeared out DM in disc.

Peaks in Gamma ray angular distribution can be described by the Dark Matter which is clustered in a way similar to the visible matter and produce spiral arms or caustic rings.

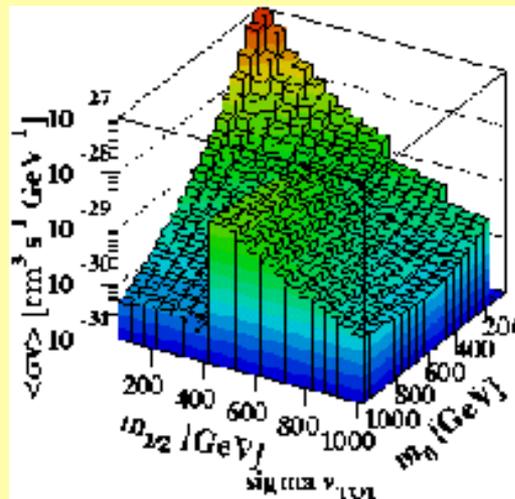
Consistency of gammas, positrons and antiprotons with a SINGLE halo profile and the SAME MSSM parameters are an interesting hint that **DM may indeed be the supersymmetric partner of CMB!**

THERMALLY AVERAGED X-SECTIONS

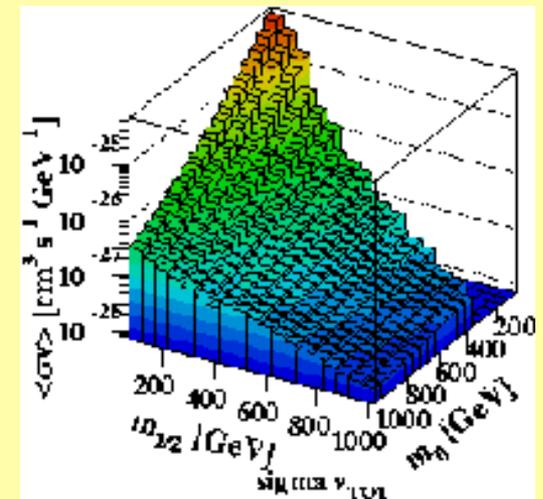
$$\langle \sigma v \rangle = \frac{\int_0^\infty dp p^2 4p \sqrt{4p^2 + 4m_\chi^2} K_1\left(\frac{\sqrt{4p^2 + 4m_\chi^2}}{T}\right) \sigma(p)}{m_\chi^4 T [K_2\left(\frac{m}{T}\right)]^2}$$



$\tan \beta = 1.6$

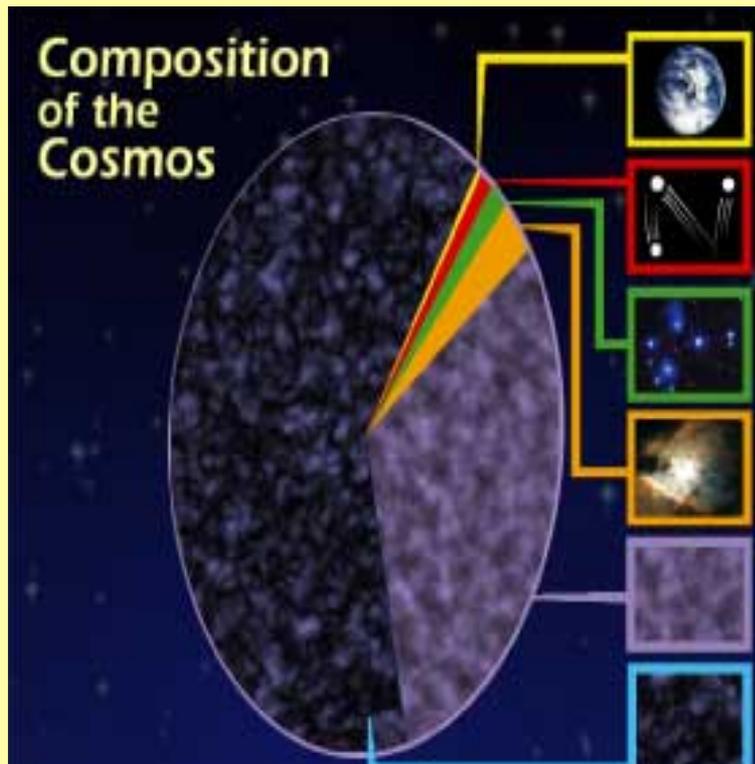


$\tan \beta = 5$



$\tan \beta = 35$

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 %