EGRET excess of diffuse galactic gamma rays as a signal of supersymmetric dark matter annihilation and related particle phenomenology

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CALCULATIONS FOR MODERN AND FUTURE COLLIDERS

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Outlook

- Introduction.
- Evidence for Dark Matter. Types of Dark Matter.
- EGRET data: an excess of the diffuse gamma ray flux
- Dark matter distribution in the Milky Way. Halo density profile. Halo substructure. The Milky Way rotation curve.
- Positrons and antiprotons in the cosmic rays
- WMAP and EGRET constraints in Constrained Minimal Supersymmetric Standard Model
- Conclusions

Evidence for the Dark Matter

- First evidence for the dark matter – motion of galaxies within clusters (F.Zwicky, 1933)

- The most direct evidence for the existence of large amount of the dark matter are the flat rotation curves of spiral galaxies (the dependence of the linear velocity of stars on the distance to the galactic center)

- Spiral galaxies consist of a rather thin disc and a spherical bulb in the galactic center

Evidence for the Dark Matter

- From the equality of forces one gets

$$F_{grav} = \frac{G M_* M_r}{r^2} = \frac{M_* v^2}{r} = F_{centr}$$

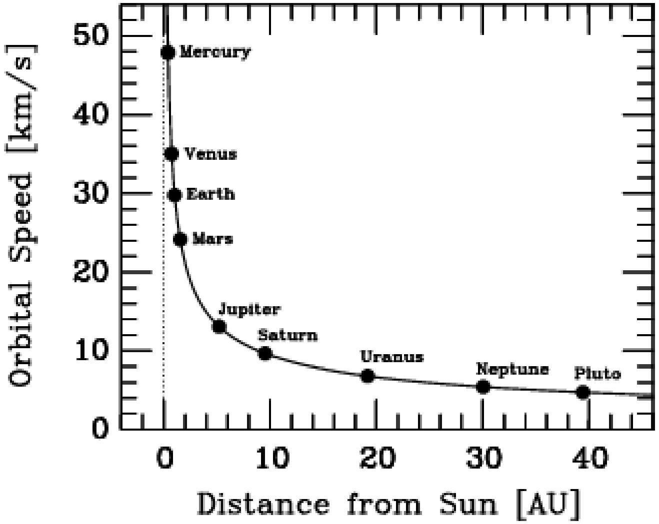
$$v(r) = \sqrt{\frac{G M_r}{r}}$$

- Assuming spherical distribution of mass in the core one gets

$$M_r = \frac{4}{3}\pi r^3 \rho$$

$v(r) \propto r$ inner part

$v(r) \propto r^{-1/2}$ outer part

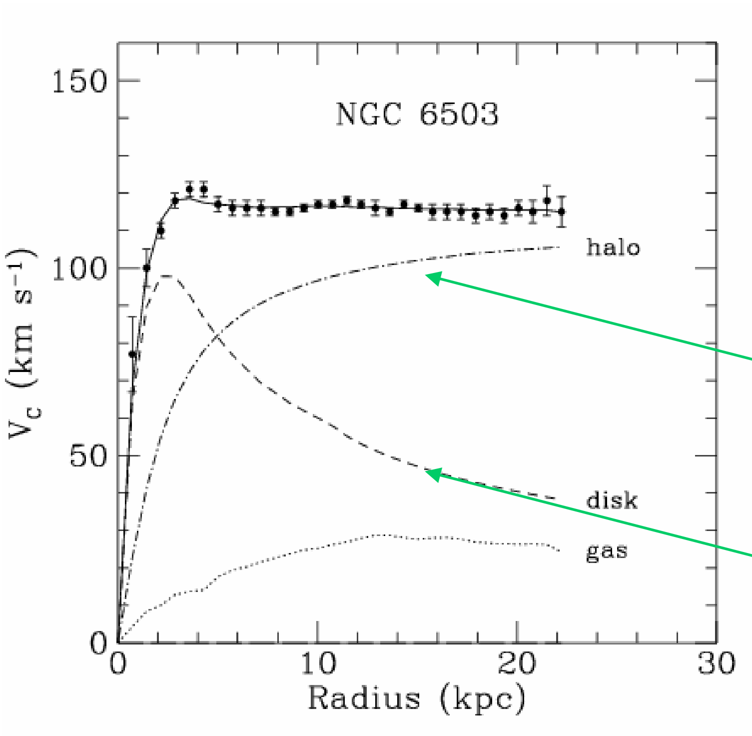


Solar system rotation curve

Evidence for the Dark Matter

- Observation tell us that for large radii *r* $v(r) \propto const$

  which means linear distribution of mass $M_r \propto r$



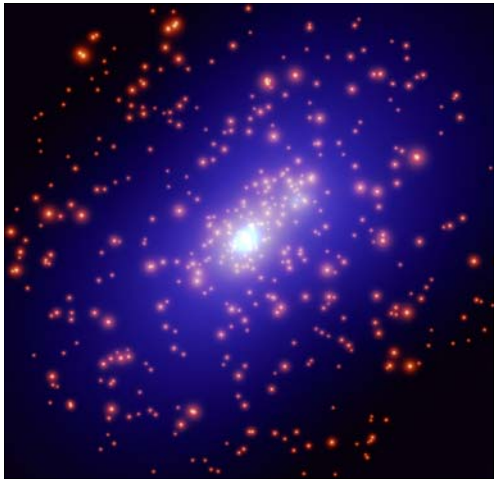
This points to the existence of the huge amount of dark matter surrounding the visible part of the galaxy

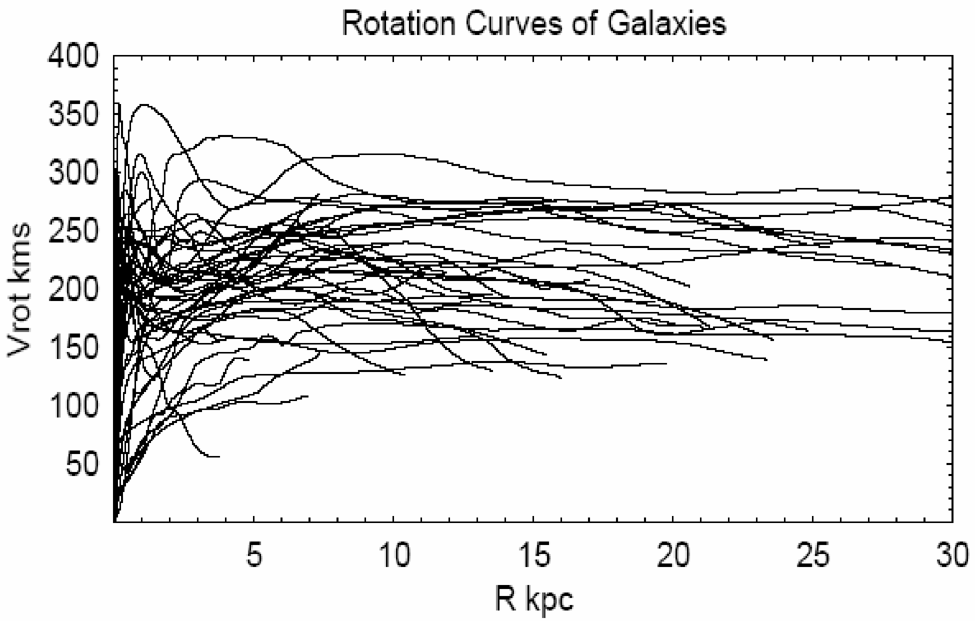
Contribution of the dark matter halo alone

Contribution of the disc (visible stars) alone

Evidence for the Dark Matter

- Nowadays, thousands of galactic rotation curves are known, and they all suggest the existence of about ten times more mass in the halos than in the stars of the disc

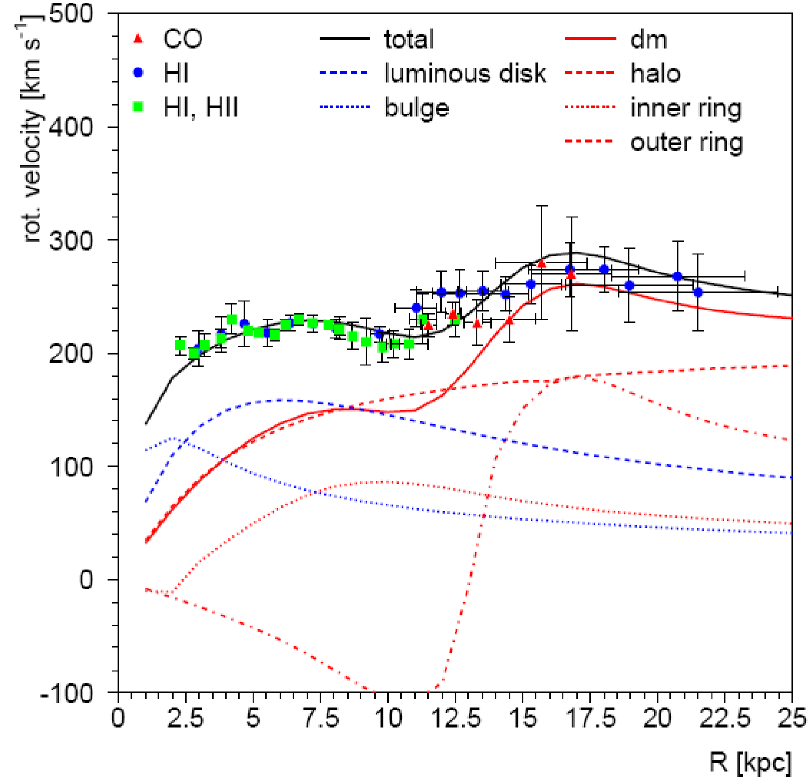




Elliptic galaxies and cluster of galaxies also contain a large amount of the dark matter

Evidence for the Dark Matter

- The Milky Way rotation curve has been measured and confirms the usual picture
- Measurements of velocities of Magellanic Clouds tells that the Milky Way has very large and massive halo
- VIRGOHI21 object – a galaxy, consisting only of dark matter



WMAP

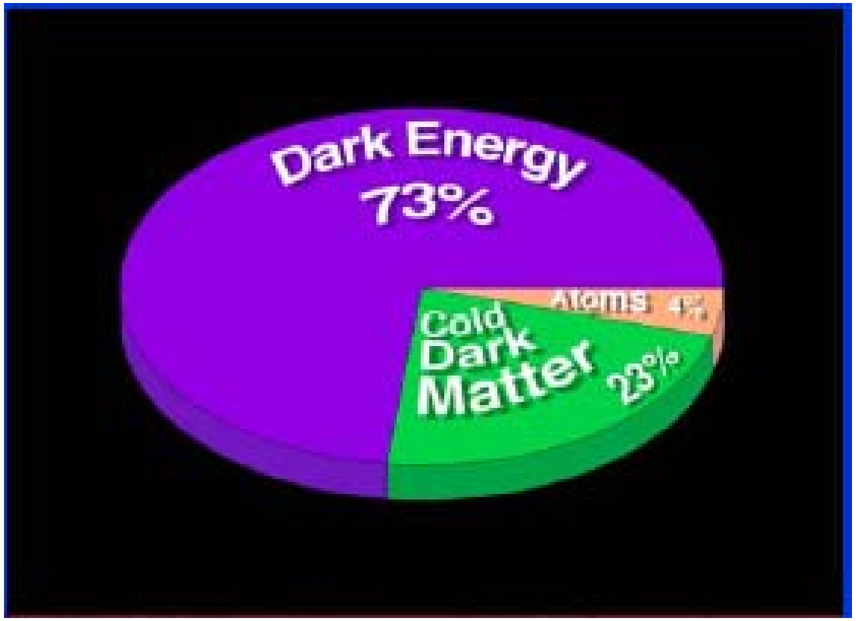
- Results of WMAP

$\rho/\rho_c \simeq 1; \quad \Omega_b = 0.044 \pm 0.004; \quad \Omega_m = 0.27 \pm 0.04; \quad \Omega_\Lambda = 0.73 \pm 0.04; \quad h = 0.71^{+0.04}_{-0.03}$

$0.094 < \Omega_{CDM} h^2 < 0.129 \, (95\% CL)$ *C. L. Bennett et al. ApJS.148:97,'03, D. N. Spergel et al. ApJS.148:175,'03*

Combination with other cosmic experiments gives

$$\Omega_{DM} h^2 = 0.113 \pm 0.009$$



Matter content of the Universe

- The matter content of the Universe is determined by the mass density parameter Ω_M. the possible contributions are

$$\Omega_M = \Omega_{B,lum} + \Omega_{B,dark} + \Omega_{CDM} + \Omega_{HDM}$$

The luminous baryonic matter (stars in galaxies)

The dark baryonic matter (MAssive Compact Halo Objects - MACHOs ?)

The cold dark matter (Weakly Interacting Massive Particles - WIMPs - neutralinos ?)

The hot dark matter (massive neutrinos ?)

Dark Matter candidates

- Non-baryonic "hot" dark matter
  - Massive neutrinos

Today we have a convincing evidence of neutrino oscillations. This means that neutrinos have a mass. The measurable quantity – mass-squared difference. $\Delta m^2 \sim 10^{-3}\ eV^2$

If neutrino mass is as large as $m \sim 0.1\ eV$, their contribution to the total density of the Universe is comparable to the contribution of the luminous baryonic matter!

$$0.001 < \Omega_{HDM(\nu)} h^2 < 0.018$$

Dark Matter candidates

- Non-baryonic "cold" dark matter

  The most reasonable explanation –

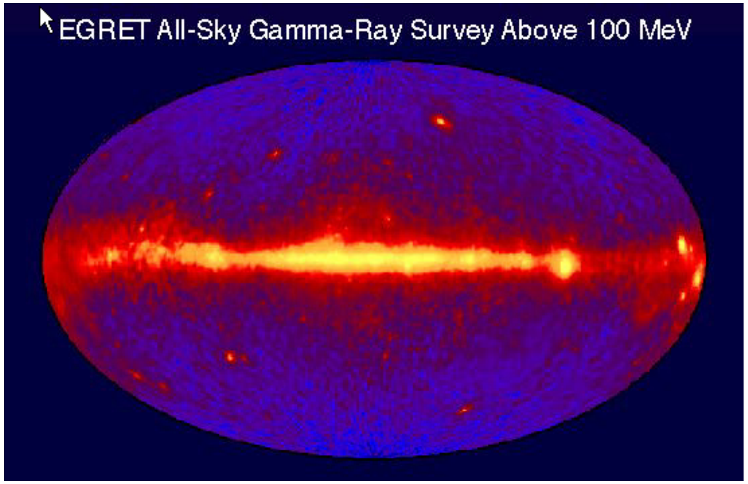
  weakly interacting massive particles (WIMP's)

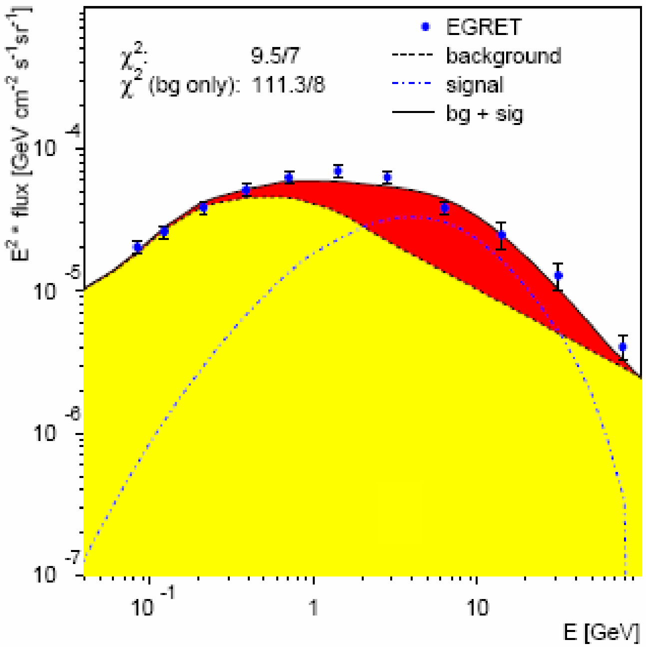
  WIMP's could have been produced in the Big Bang origin of the Universe in the right amounts and with the right properties to explain the Dark Matter

  BUT: we do not know WHAT the WIMP IS

EGRET Excess

- EGRET Data on diffuse Gamma Rays show excess in all sky directions with the same energy spectrum from monoenergetic quarks





- 9 yrs of data taken (1991-2000)

- Main purpose: sky map of point sources above diffuse background.

EGRET Excess

A: Inner Galaxy (l=±30^0, |b|<5^0)

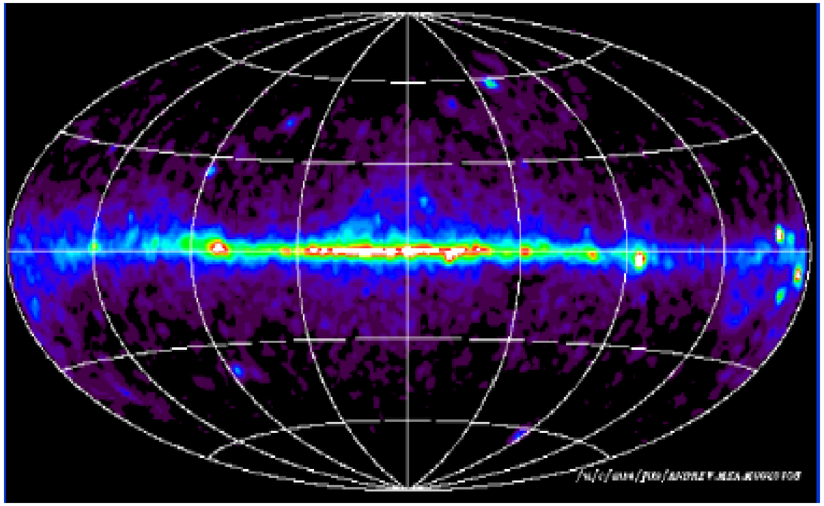
B: Galactic plane avoiding A (30-330^0)

C: Outer Galaxy (90-270^0)

D: Low latitude (10-20^0)

E: Intermediate lat. (20-60^0)

F: Galactic poles (60-90^0)



Region	l, degrees	$\|b\|$, degrees
A	330–30	0–5
B	30–330	0–5
C	90–270	0–10
D	0–360	10–20
E	0–360	20–60
F	0–360	60–90

Excess has the same shape implying the same source everywhere in the galaxy

EGRET Excess

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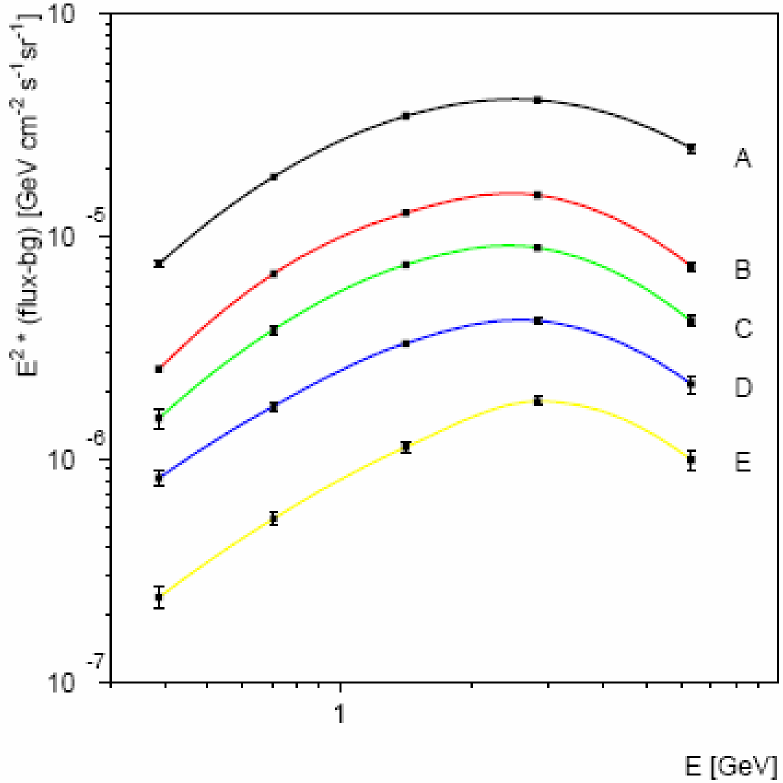

Excess has the same shape implying the same source everywhere in the galaxy

EGRET gamma excess above extrapolated background from data below 0.5 GeV

EGRET Excess

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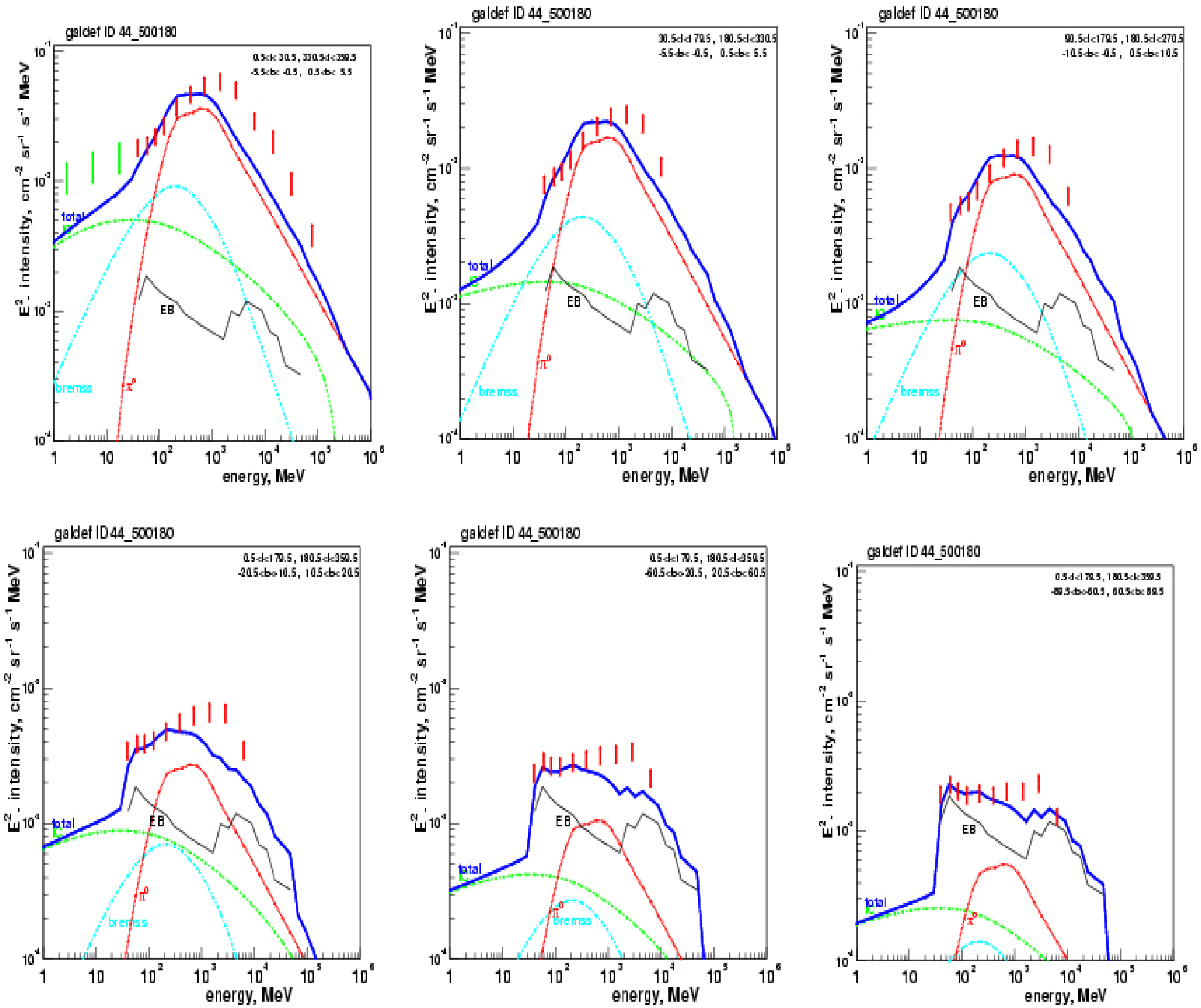
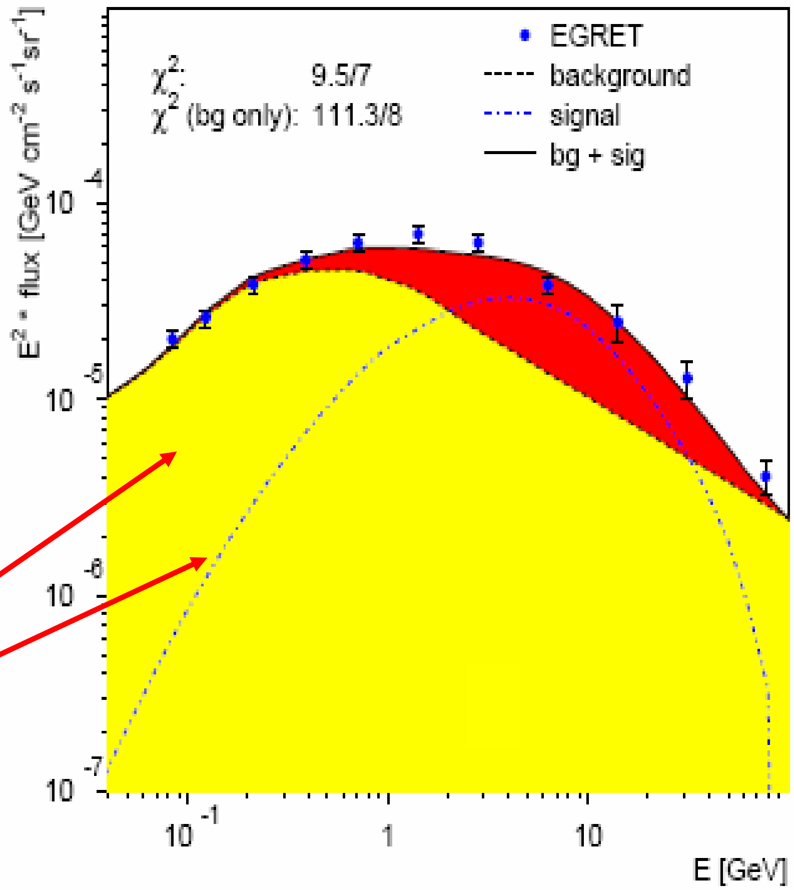


EGRET Excess vs WIMP annihilation

- The excess of diffuse gamma rays is compatible with WIMP mass of 50 -100 GeV

- Region A: inner Galaxy ($l=\pm 30^0$, $|b|<5^0$)

Background
WIMP contribution



EGRET Excess vs WIMP annihilation

A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)

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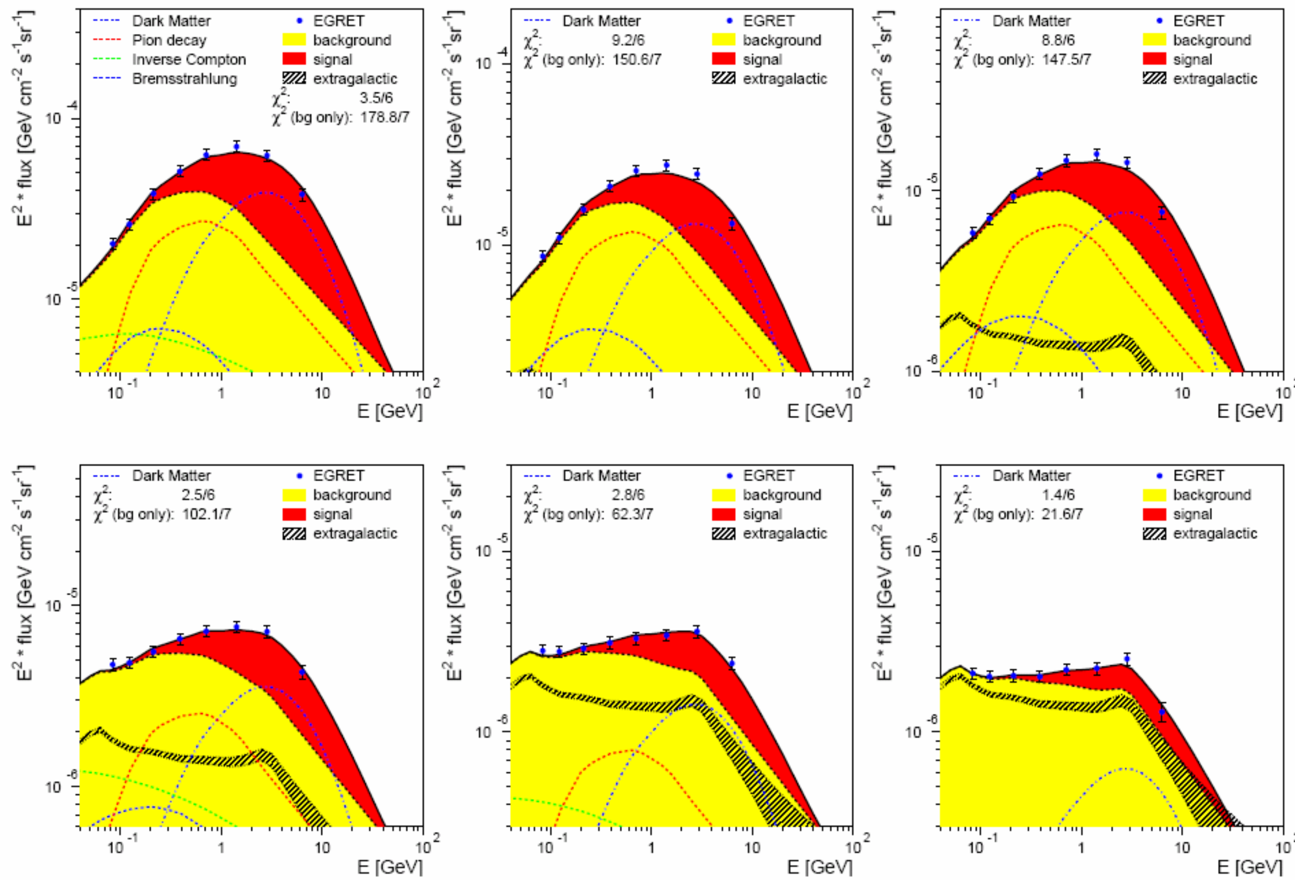
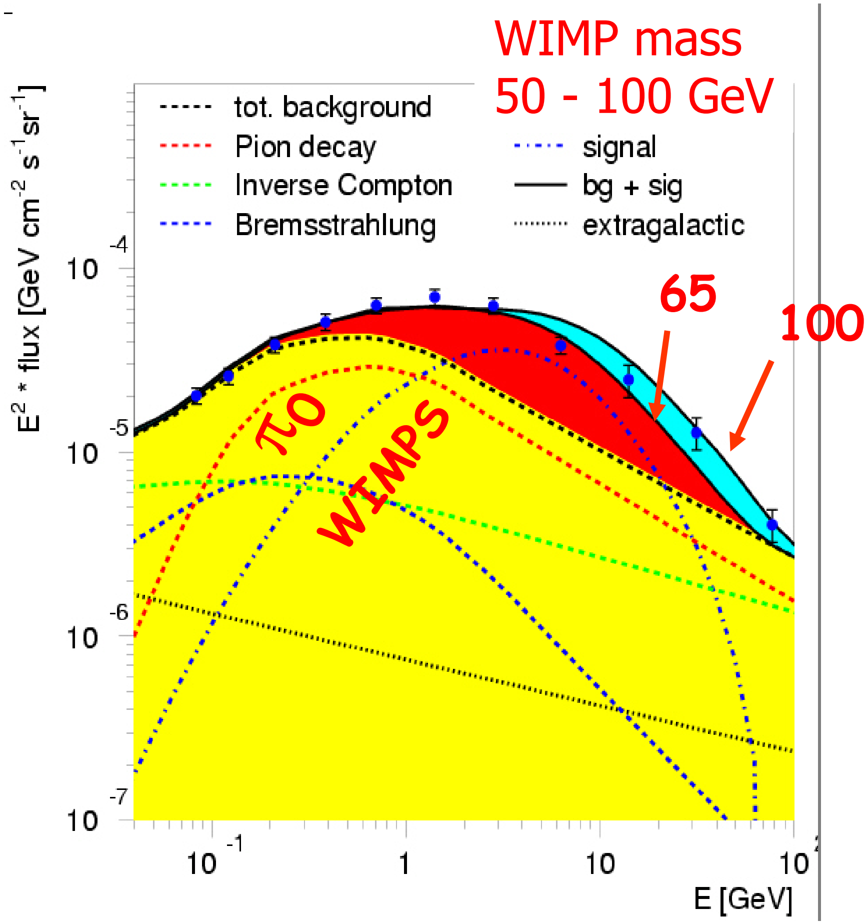


EGRET Excess vs WIMP annihilation

- 3 components (galactic background + extragalactic background + DM annihilation) fitted simultaneously with same WIMP mass and DM normalization in all directions.

- **Blue:** uncertainty from WIMP mass



Determination of halo profile

- The differential gamma flux in a direction forming an angle ψ with the direction of the galactic center is given by:

differential photon yield for the final state f

Dark matter mass density

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

WIMP annihilation cross section

branching ratio into the tree-level annihilation final state f

Boostfactor

WIMP mass

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \approx \left(\frac{2\cdot 10^{-27} cm^3 s^{-1}}{< \sigma v >}\right).$$

Determination of halo profile

- A survey of the optical rotation curves of 400 galaxies shows that the halo distributions of most of them can be fitted either with the Navarro-Frank-White (NFW) or the pseudo-isothermal profile.
  The halo profiles can be parametrized as follows:

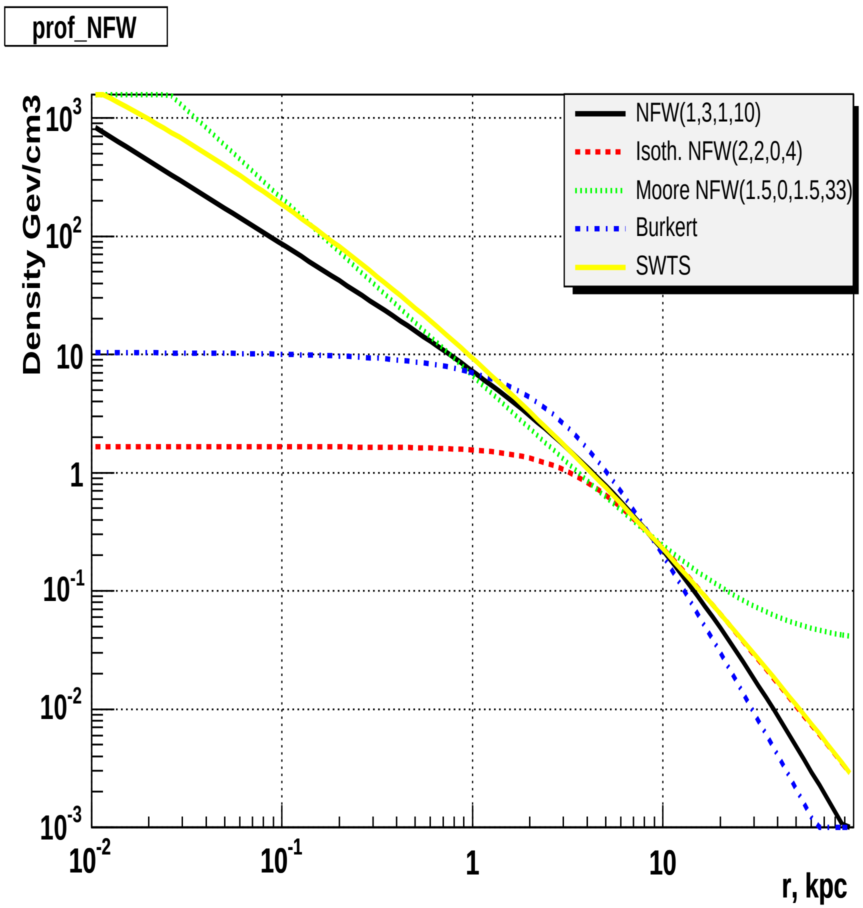
$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} \qquad \tilde{r} = \sqrt{\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}},$$

a is a scale radius,

α, β, γ define behaviour at $r \approx a$, $r >> a$ and $r << a$

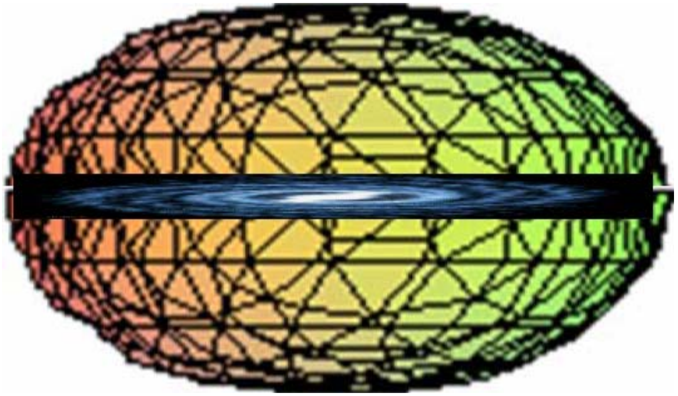
Determination of halo profile

- Navarro-Frank-White profile
  (1,3,1) very cuspy
- Moore profile
  (1.5,0,1.5) very cuspy
- Isotermal profile
  (2,2,0) less cuspy
  β=2 implies flat rotation curve

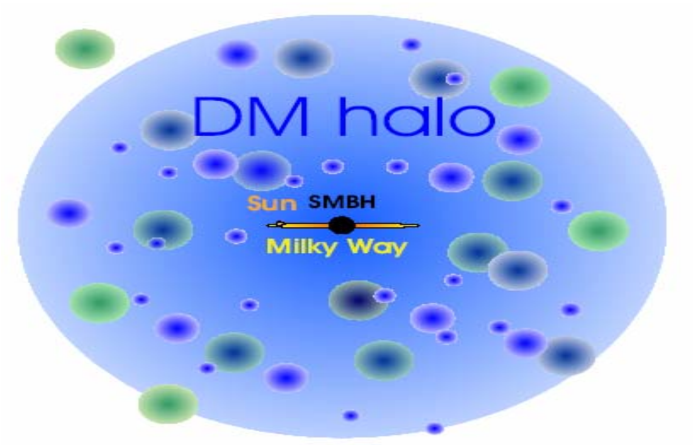


Determination of halo profile

- The spherical profile can be flattened in two directions to form a triaxial halo. N-body simulations suggest the ratio of the short (intermediate) axis to the major axis is typically above 0.5-0.7



- It is not clear if the dark matter is homogeneously distributed or has a clumpy character. Clumps can enhance the annihilation rate. This enhancement (boostfactor) can be determined from a fit to the data.



Determination of halo profile

- The possible enhancement of DM density in the disc was parametrized by a set of Gaussian rings in the galactic plane in addition to the expected triaxial profile for the DM halo. At least two rings should be envisaged: one "outer" ring and one "inner" ring. Parameters of the rings can be determined from a fit to the data.

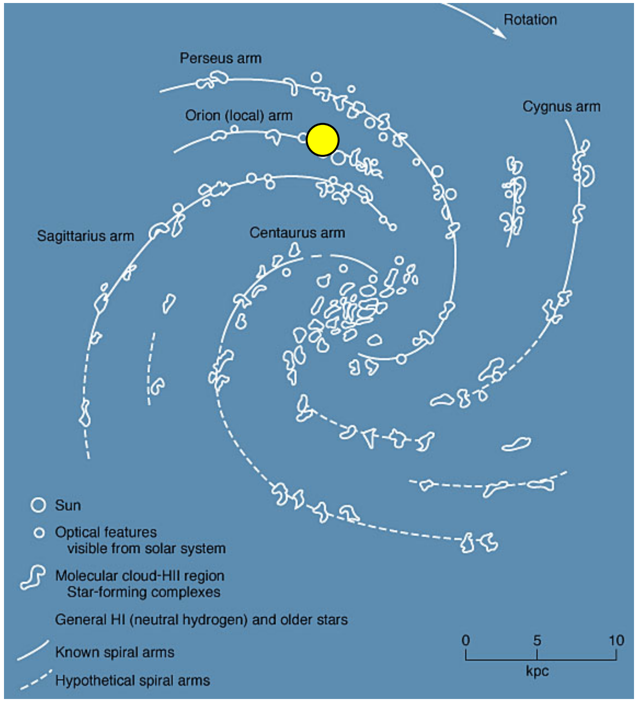
$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N=2} \rho_n \exp\left(-\frac{\left(\tilde{r}_{gc}-Rn\right)^2}{2\sigma_{R_n}^2} - \frac{\left(z_n\right)^2}{2\sigma_{z_n}^2}\right)$$

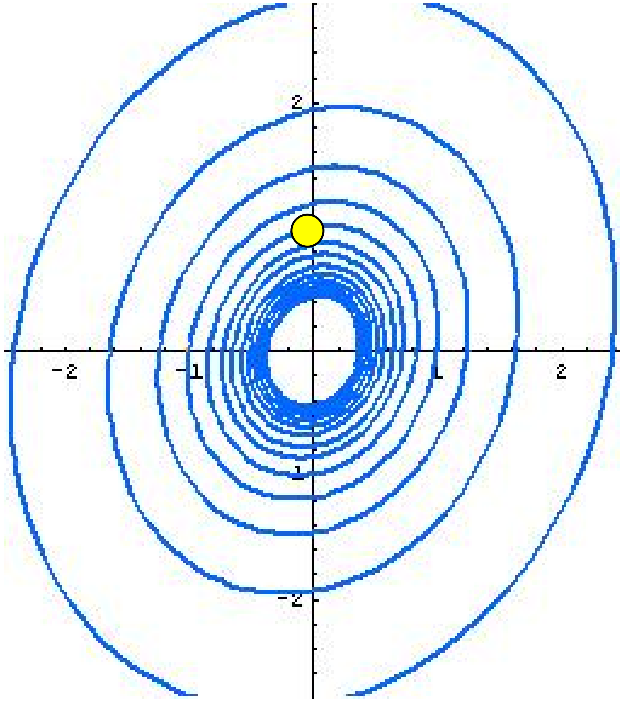
$\propto$ **1/r²** — **2 Gaussian ovals**

$$\tilde{r} = \sqrt{\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}}, \qquad \tilde{r}_{gc} = \sqrt{\frac{x^2}{\tilde{a}^2}+\frac{y^2}{\tilde{b}^2}},$$

Determination of halo profile

- Spiral structure
- Caustic rings



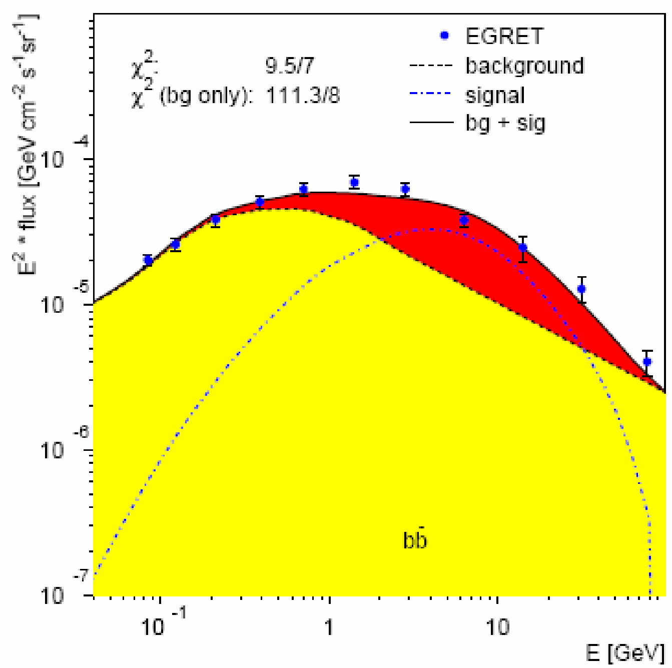


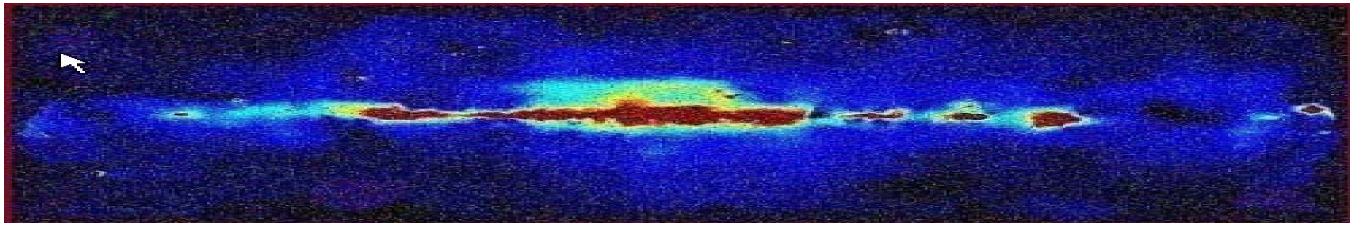
Determination of halo profile

- Parameters in halo profile fitted by requiring minimal difference between boostfactors of various regions.
- If clustering is similar in all directions (same boostfactors everywhere), then the excess of diffuse gamma rays is $\sim\langle\rho\rangle^2$ along the line of sight.
- $\langle\rho\rangle$ is determined by the halo profile, which is normalized to the local dark matter density ρ_0.
- ρ_0 can be estimated from the rotation curve to be 0.3 GeV/cm^3 for a spherical profile and R_0 = 8.5 kpc. For a non-spherical one the density has to be rescaled.

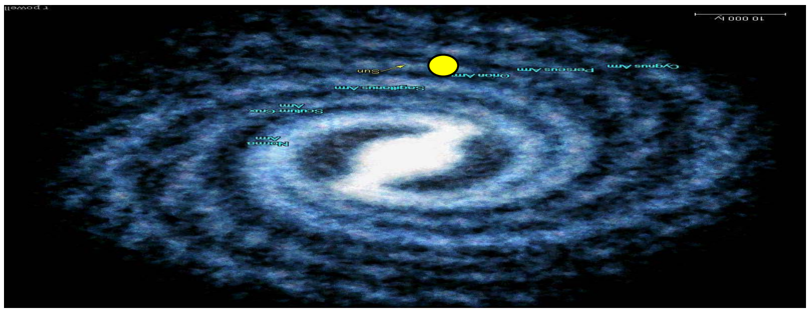
Determination of halo profile

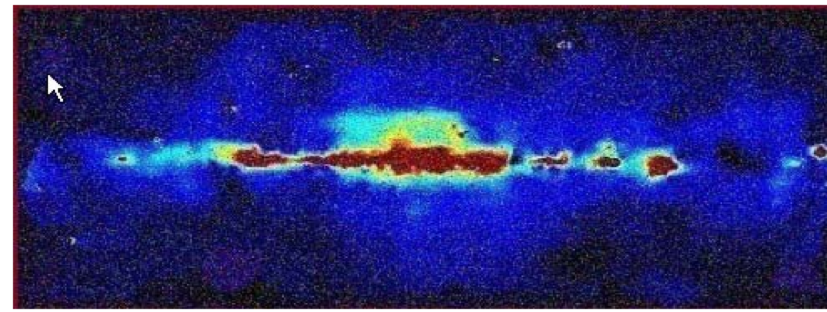
- Energy spectrum of diffuse gamma rays is well described by background + WIMP annihilation
- Longitude and lattitude distributions (different sky directions!) of gammas are used for determination of halo and substructure (rings) parameters

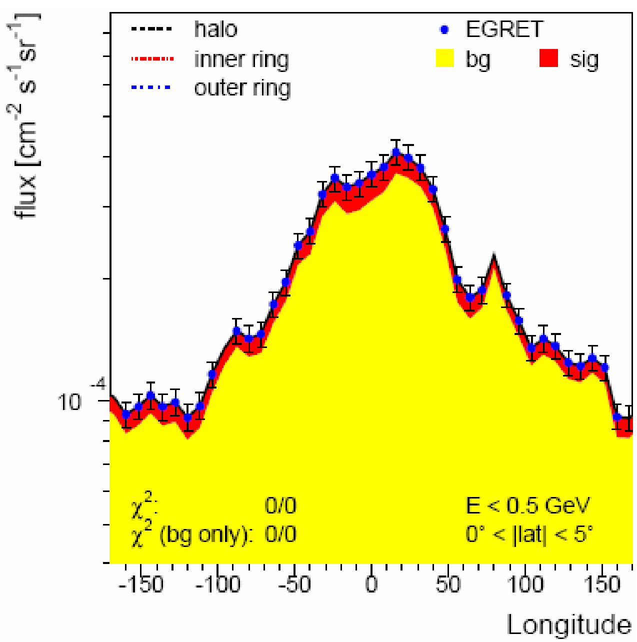


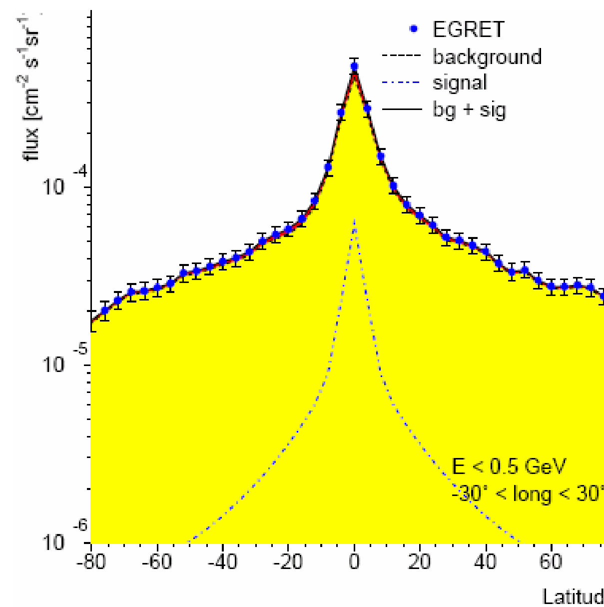


Gammas below 0.5 GeV (EGRET)

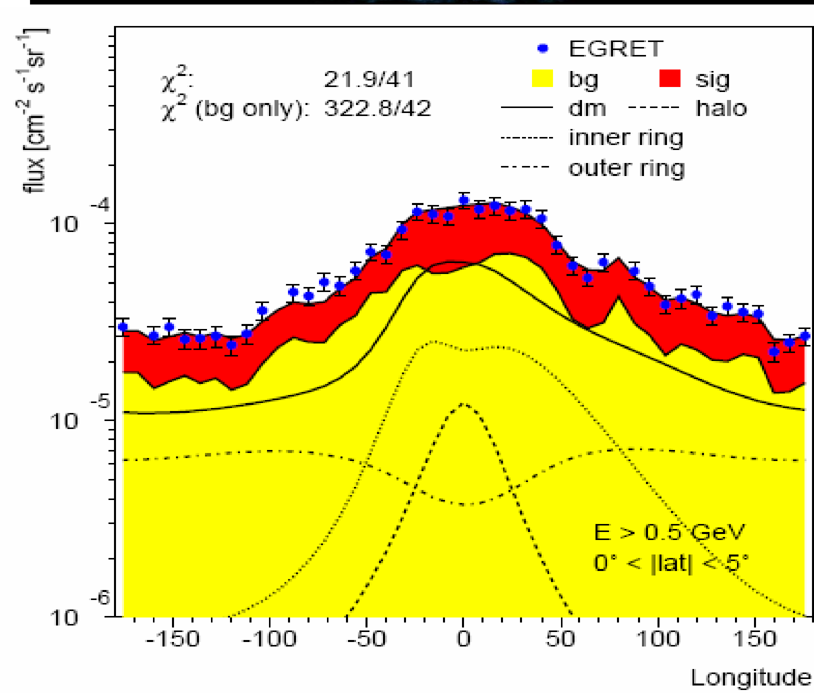


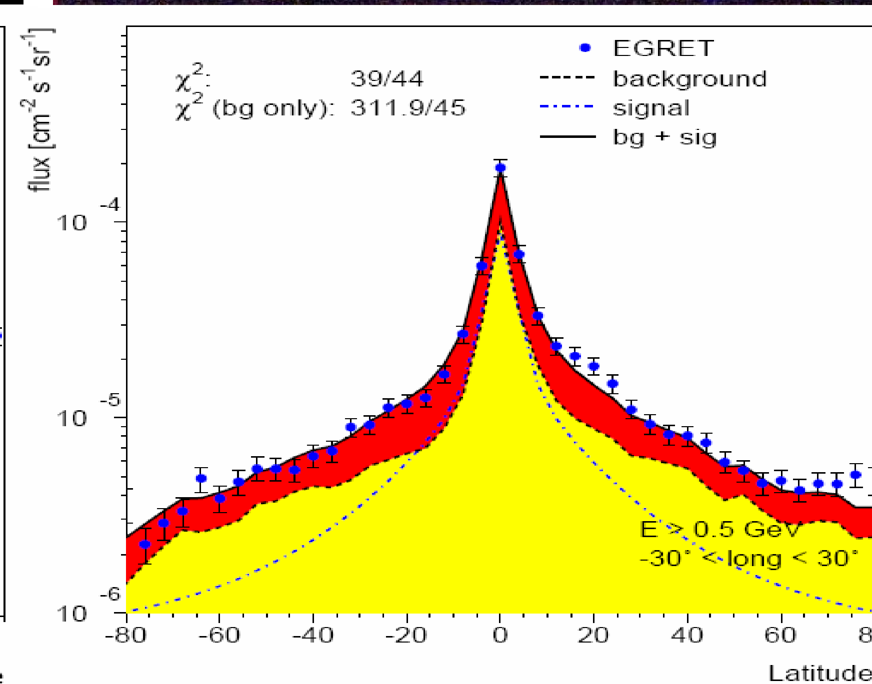






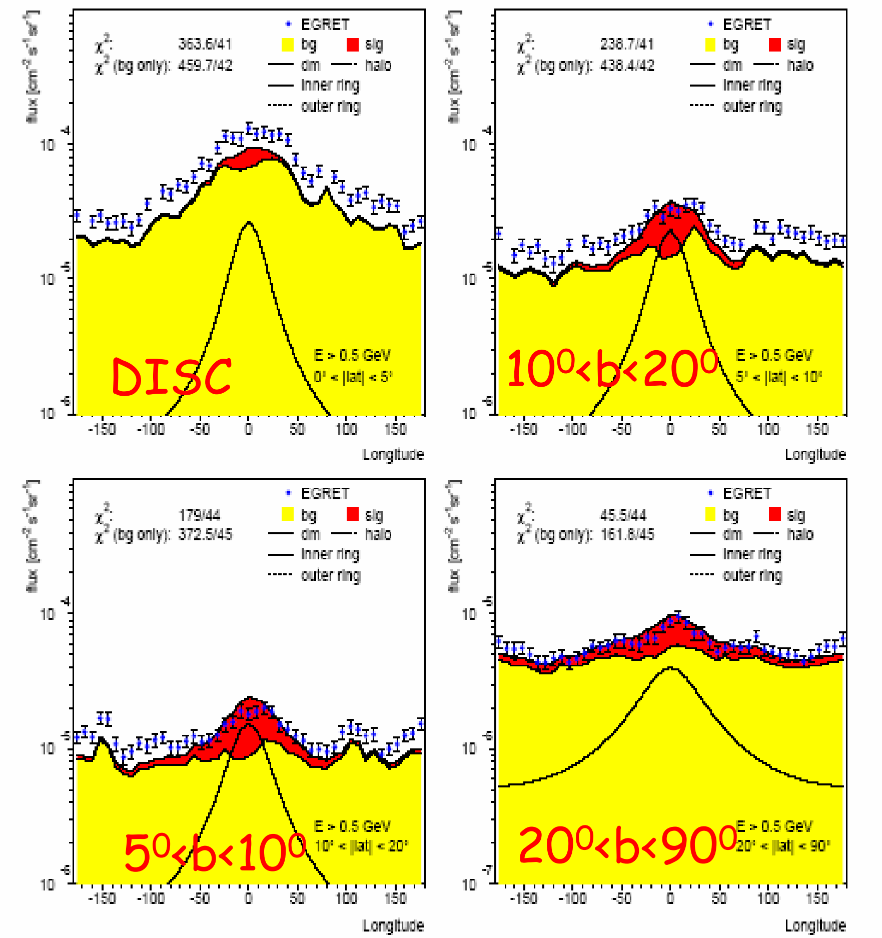
Gammas above 0.5 GeV (EGRET)





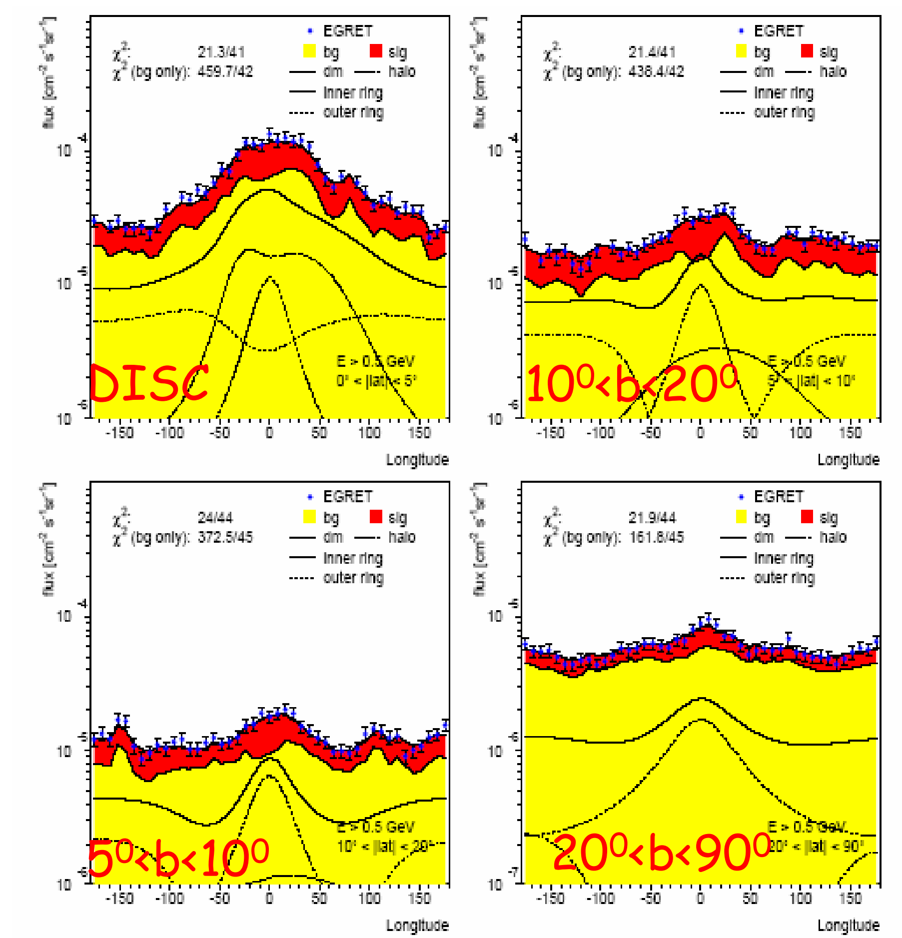
Fits for 1/r² profile with/without rings

WITHOUT rings



Fits for $1/r^2$ profile with/without rings

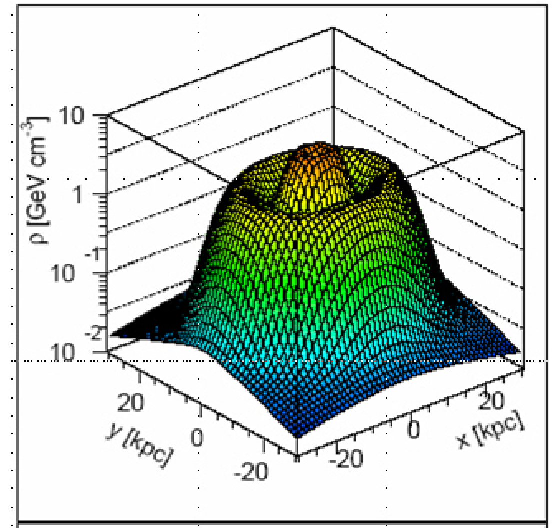
WITH 2 rings



Fit results for halo profile

Fit results of halo parameters

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	1.2-2.1 GeV cm^{-3}
a	4 kpc	R_b	$14\ kpc$
ρ_0	0.42 GeV cm^{-3}	$\sigma_{R,b}$	$2.1\ kpc$
ρ_a	1.8-3.3 GeV cm^{-3}	$\sigma_{z,b}$	$1.3\ kpc$
b/a	0.9	c/a	0.8

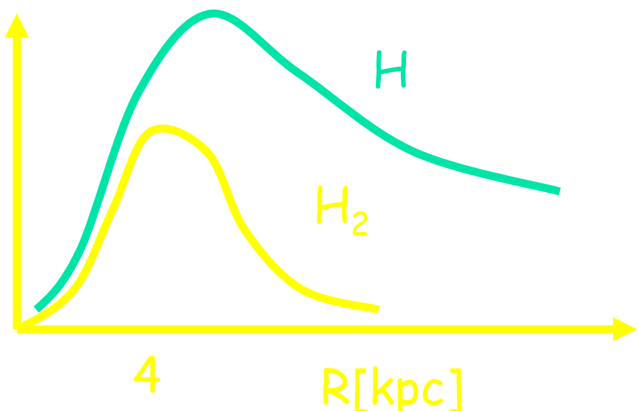


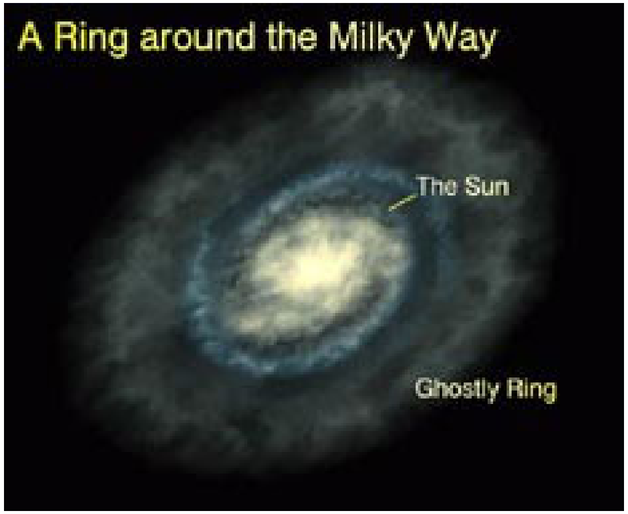
Enhancement of rings over $1/r^2$ profile 2 and 7, respectively.

Mass in rings 1.6% and 0.3% of total Dark Matter

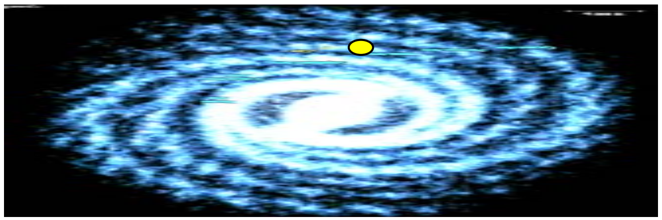
Determination of halo profile

- 14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy (Yanny, Ibata, ….., 2003)
- 4 kpc coincides with ring of neutral hydrogen molecules!

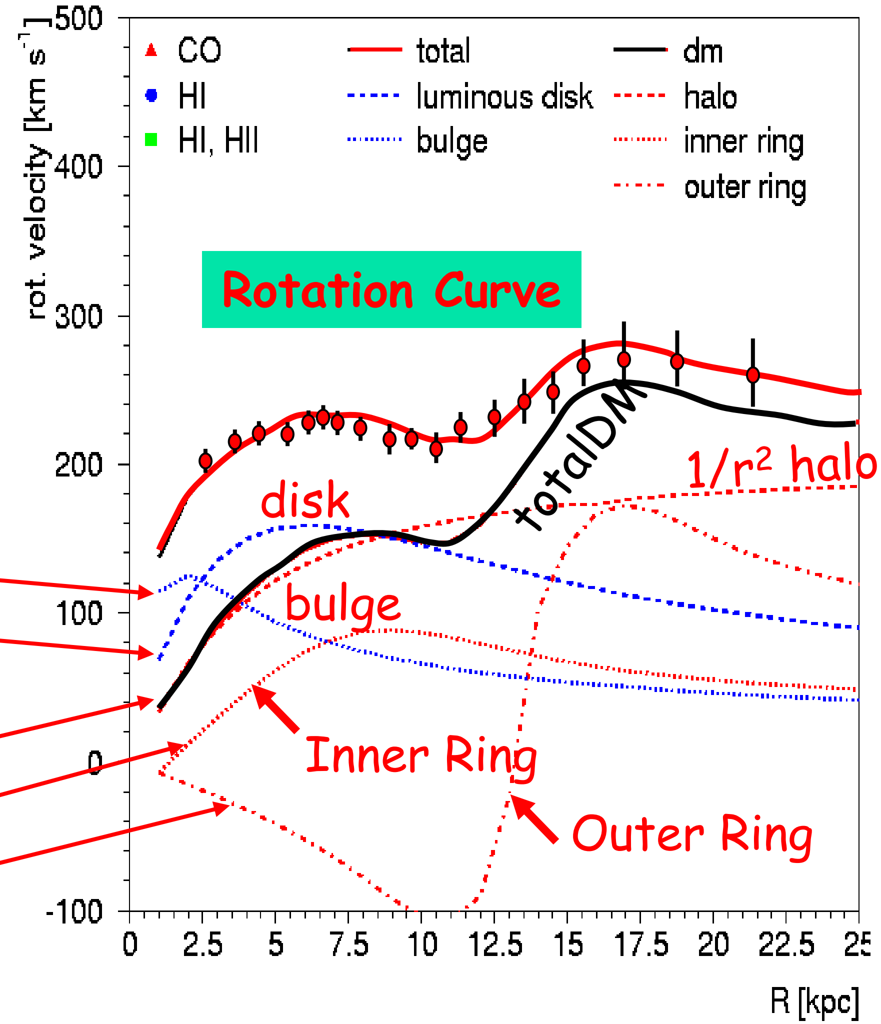




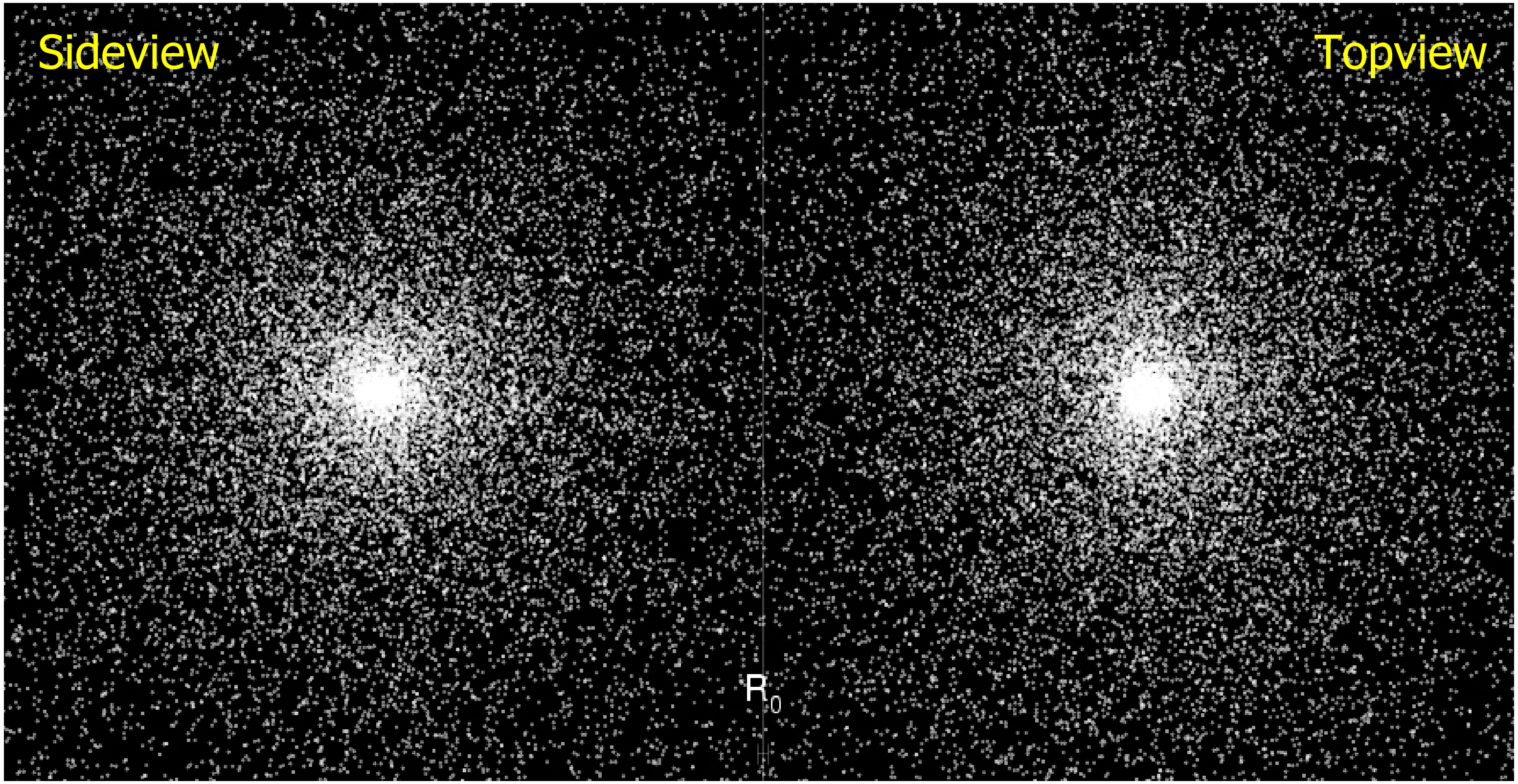
The Milky Way rotation curve



- Contributions to the rotation curve of the Milky Way from
  - Visible bulge
  - Visible disk
  - Dark halo
  - Inner dark ring
  - Outer dark ring

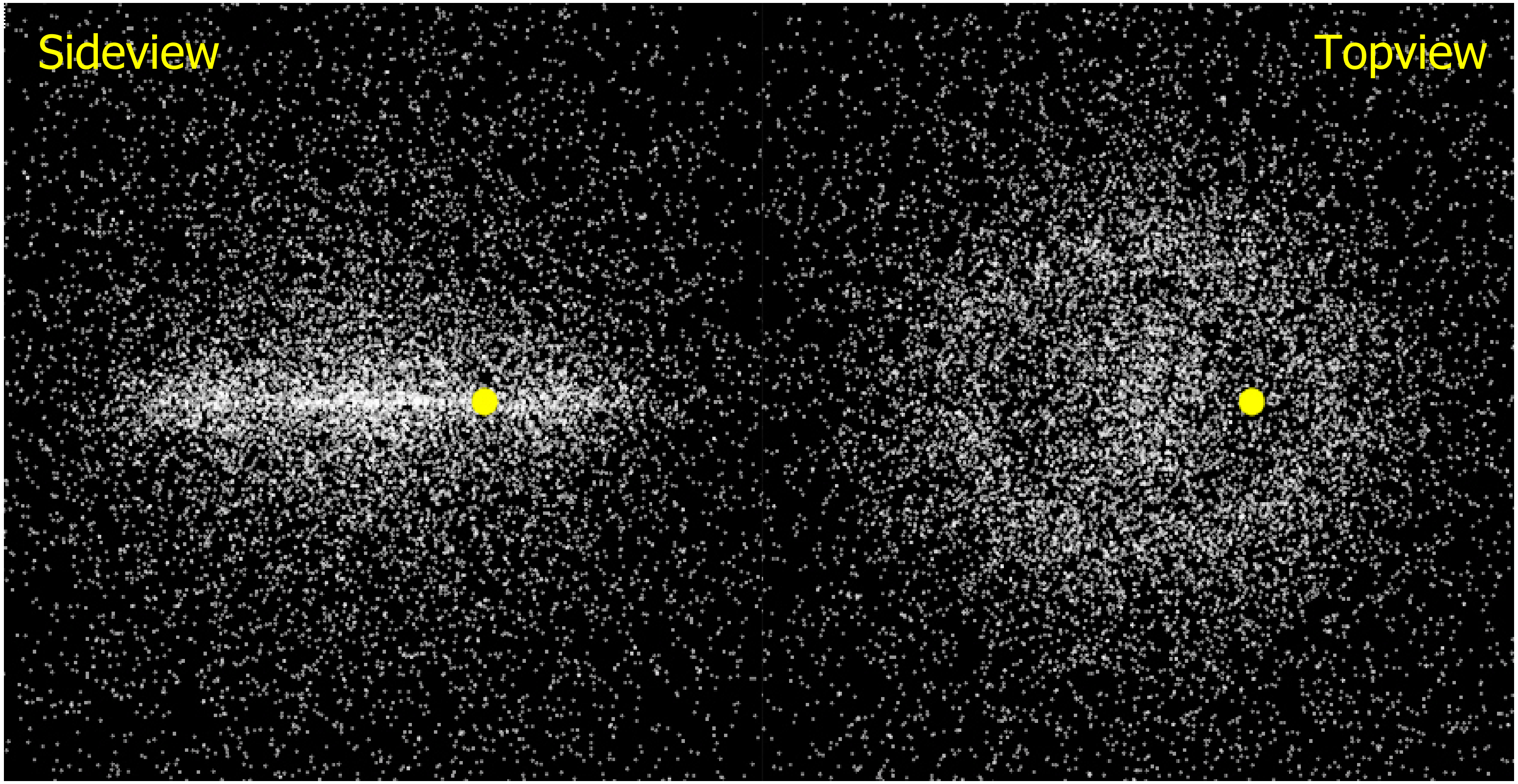


Halo density at 300 kpc



Cored isothermal halo profile. Total mass: 3×10^{12} solar masses

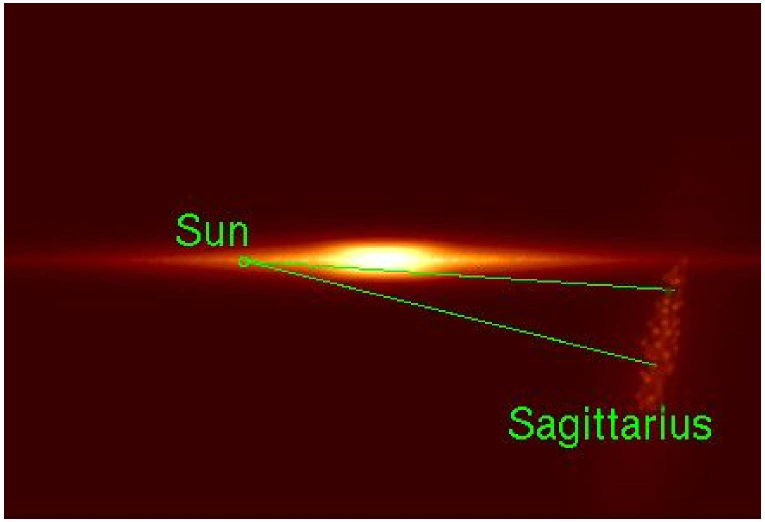
Halo density at 30 kpc



Ring halo substructure. R ~ 4 and 14 kpc.

Possible origin of rings

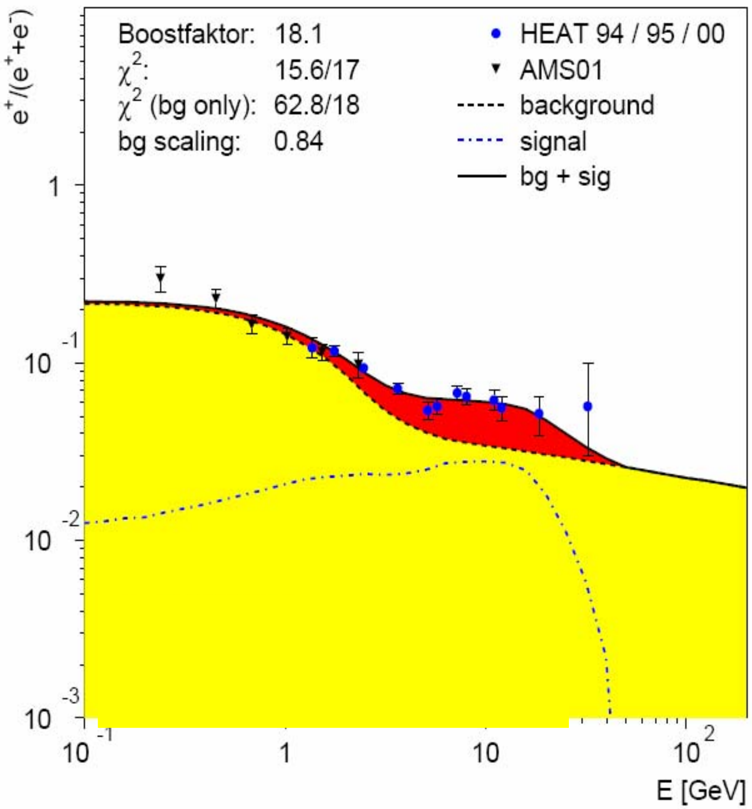
- In 1994 Cambridge astronomers discovered a highly distorted dwarf galaxy in the Sagittarius constellation. The galaxy falls towards the Milky Way spreading out stars along its pass.

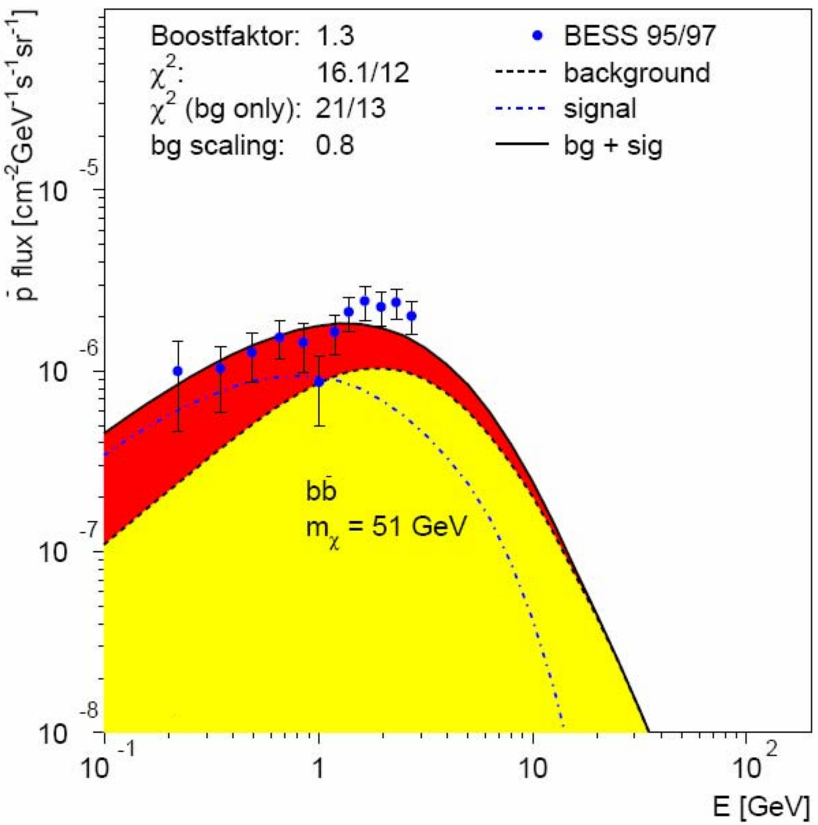


- In 2003 Canis Major dwarf galaxy was discovered

- In 2003 a giant stellar structure surrounding the Galaxy was discovered (possibly the remnant of a galaxy “eaten” by Milky Way very long ago)

Positrons and antiprotons in cosmic rays





- SAME halo and WIMP parameters as for gamma rays

Neutralino – SUSY dark matter

- Still we know nothing about WIMP
- Supersymmetry helps again

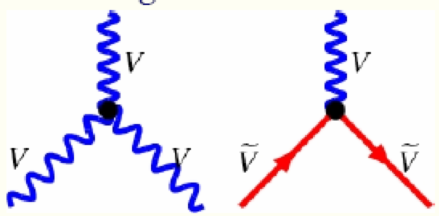
	Superfield	Bosons	Fermions	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge	$\mathbf{G^a}$	gluon g^a	gluino $\tilde{g}^a$	8	1	0
	$\mathbf{V^k}$	Weak W^k $(W^\pm, Z)$	wino, zino $\tilde{w}^k$ $(\tilde{w}^\pm, \tilde{z})$	1	3	0
	$\mathbf{V'}$	Hypercharge B (γ)	bino $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter	$\mathbf{L_i}$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

Neutralino – SUSY dark matter

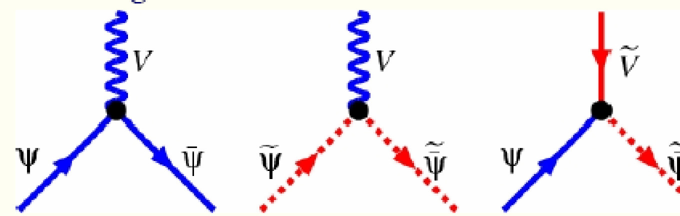
- Lagrangian of the Minimal Supersymmetric Standard Model:

$\mathcal{L} = \mathcal{L}_{SUSY} + \mathcal{L}_{Breaking},$ where $\mathcal{L}_{SUSY} = \mathcal{L}_{Gauge} + \mathcal{L}_{Gauge-matter} + \mathcal{L}_{matter}$

$$\mathcal{L}_G = \sum_G$$

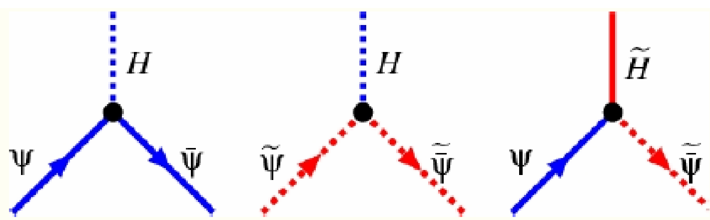


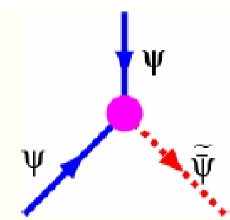
$$\mathcal{L}_{G-m} = \sum_m$$



- Yukawa interactions

$$\mathcal{L}_m = \int d^2\theta\,(W_R + W_{NR}) + h.c$$



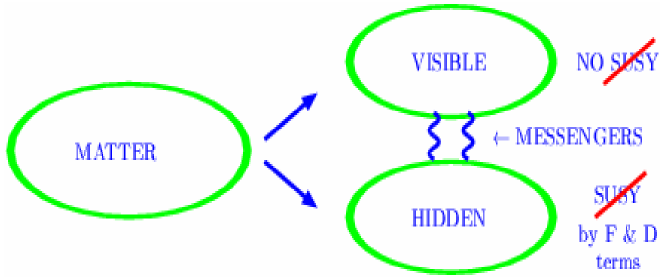


$$W_R = \varepsilon_{ij}(y^U_{ab}Q^j_aU^c_bH^i_2 + y^D_{ab}Q^j_aD^c_bH^i_1 + y^L_{ab}L^j_aE^c_bH^i_1 + \mu H^i_1H^j_2),$$

$$W_{NR} = \varepsilon_{ij}(\lambda^L_{abd}L^i_aL^j_bE^c_d + \lambda^{L\prime}_{abd}L^i_aQ^j_bD^c_d + \mu^\prime_aL^i_aH^j_2) + \lambda^B_{abd}U^c_aD^c_bD^c_d$$

Neutralino – SUSY dark matter

- Supersymmetry is a broken symmetry.



- Breaking takes place in a hidden sector. Messengers to the visible sector can be gravitino, gauge bosons, gauginos, …

- Breaking must be soft (dimension of soft SUSY breaking operators ≤ 3)

$$\mathcal{L}_{soft}^{MSSM} = \underbrace{\sum_{i,j} B_{ij}\mu_{ij}S_iS_j}_{\text{bilinear terms}} + \underbrace{\sum_{ij} m_{ij}^2 S_i S_j^\dagger}_{\text{scalar mass terms}} + \underbrace{\sum_{i,j,k} A_{ijk} f_{ijk} S_i S_j S_k}_{\text{trilinear scalar interactions}} + \underbrace{\sum_{A,\alpha} M_{A\alpha}\bar{\lambda}_{A\alpha}\lambda_{A\alpha}}_{\text{gaugino mass terms}}$$

- In total one has about a hundred parameters

Neutralino – SUSY dark matter

- Main uncertainties come from soft supersymmetry breaking parameters.
- Universality hypothesis: soft supersymmetry breaking parameters unify at the scale of Grand Unification

$$\mathcal{L}_{soft}^{MSSM} = \underbrace{\sum_{i,j} B_{ij}\mu_{ij}S_iS_j}_{\text{bilinear terms}} + \underbrace{\sum_{ij} m_{ij}^2 S_i S_j^\dagger}_{\text{scalar mass terms}} + \underbrace{\sum_{i,j,k} A_{ijk} f_{ijk} S_i S_j S_k}_{\text{trilinear scalar interactions}} + \underbrace{\sum_{A,\alpha} M_{A\alpha}\bar{\lambda}_{A\alpha}\lambda_{A\alpha}}_{\text{gaugino mass terms}}$$

- As a result one has only 5 free parameters (4 + one sign)
  - Common scalar mass m_0
  - Common gaugino mass $m_{1/2}$
  - Common soft SUSY breaking parameter A_0
  - $\tan\beta = v_2 / v_1$

Neutralino – SUSY dark matter

- Neutralino – a mixture of superpartners of photon, Z-boson and neutral Higgs bosons

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

photino zino higgsino higgsino

  - Neutral (no electric chaege, no colour)
  - Weakly interacting (due to supersymmetry)
  - The lightest supersymmetric particle
  - Stable (!) if R-parity is conserved

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

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

- Perfect candidate for dark matter particle (WIMP)

Neutralino – SUSY dark matter

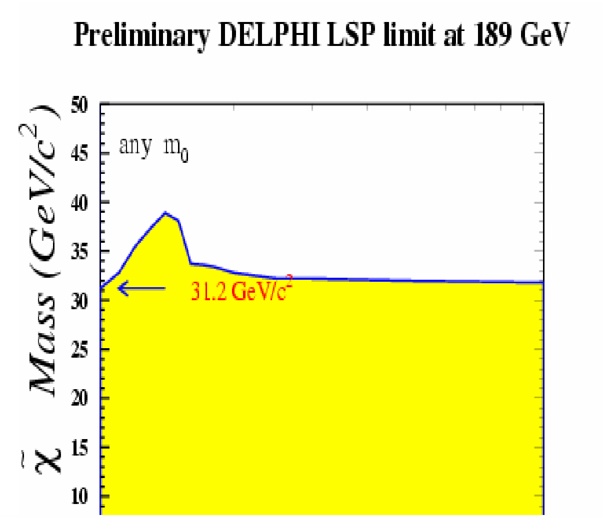
- Limits on neutralino mass

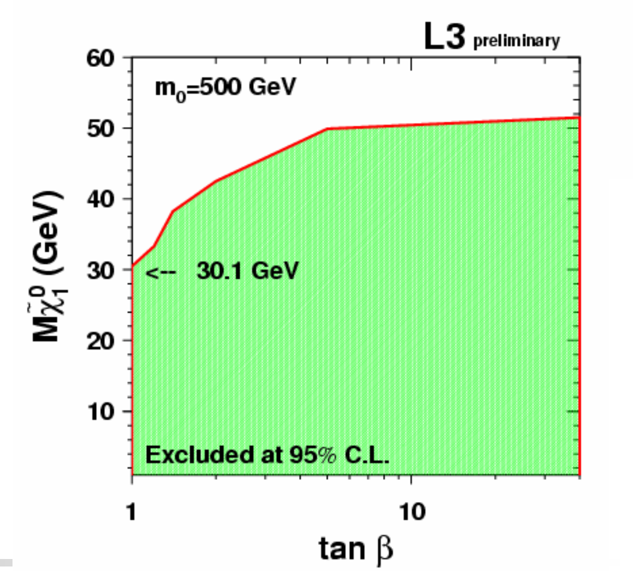
$$M_{\chi}^{\exp} \geq 40 \text{ GeV}$$

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

- Heavy enough to account for cold non-baryonic dark matter in the Universe

- Annihilation cross sections are known (at least we know how to calculate them)



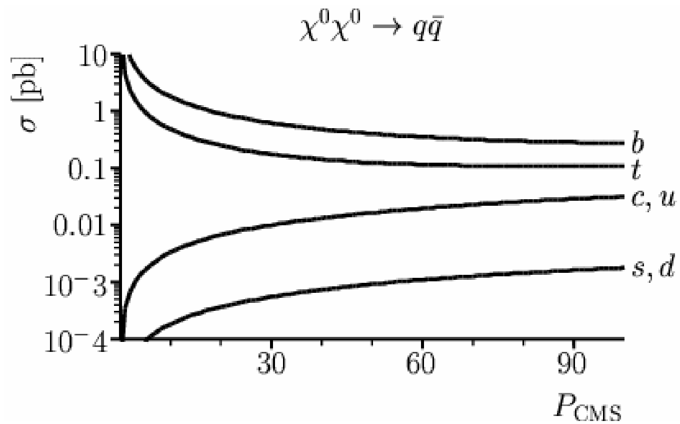


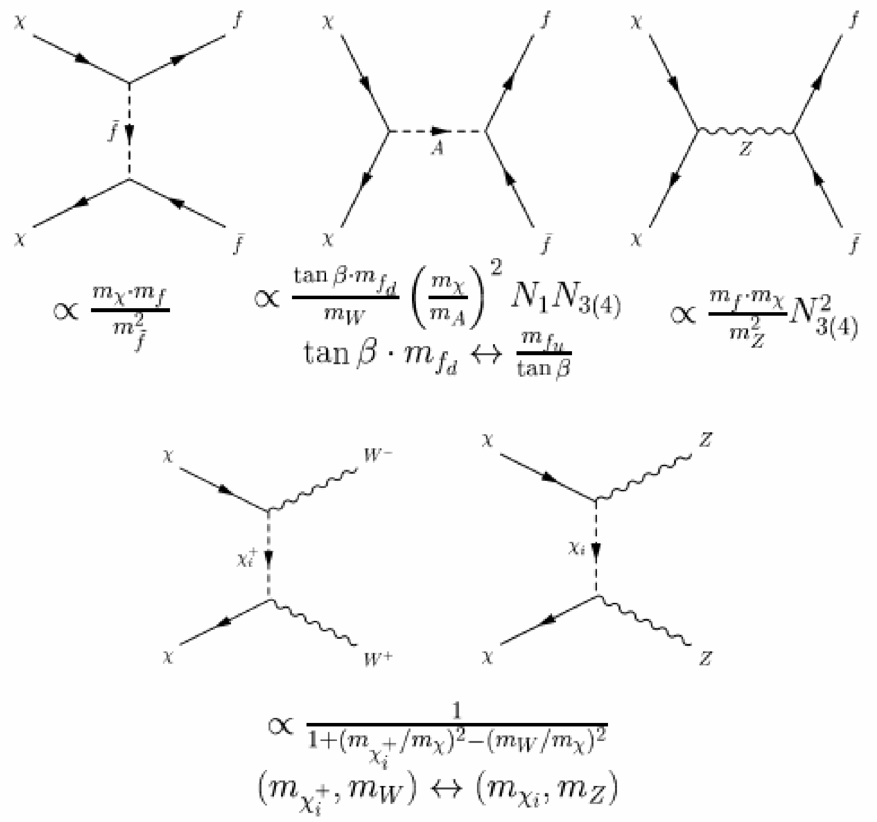
Neutralino – SUSY dark matter

- Main diagrams for neutralino annihilation

- Dominant diagram for WMAP cross section:

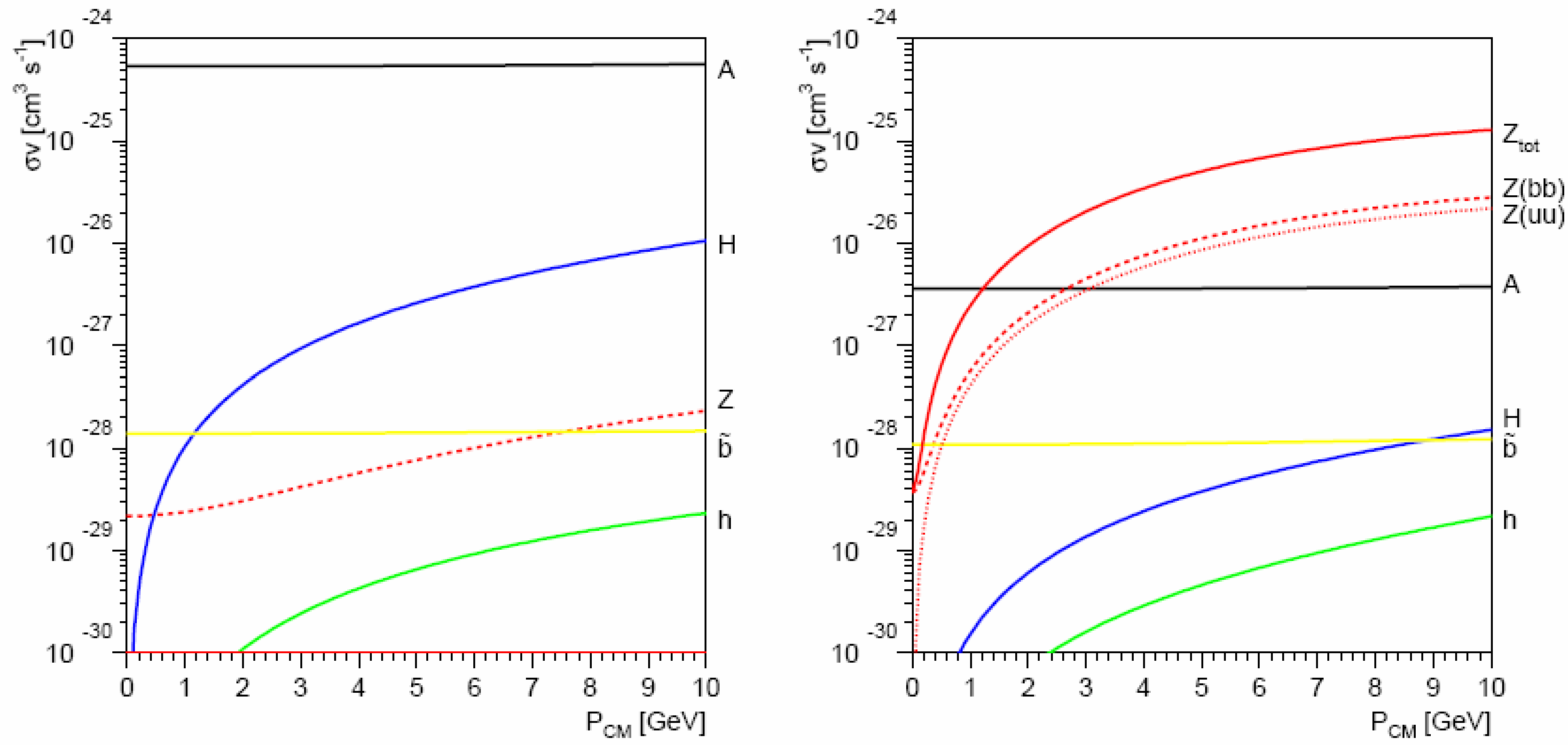
$$\chi\chi \to A \to b\bar{b}$$





Neutralino – SUSY dark matter

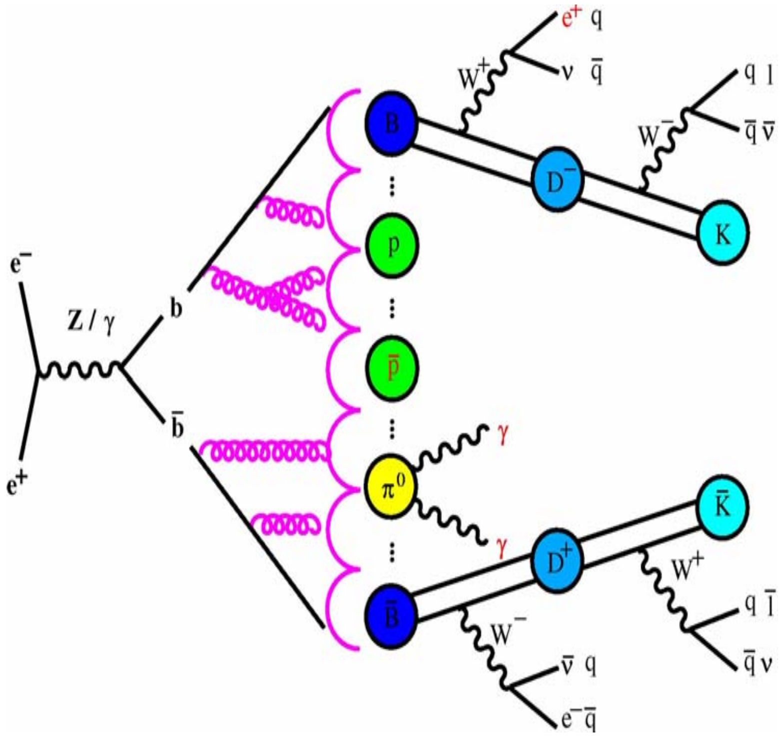
- σv for main diagrams for neutralino annihilation $\chi\chi \to A, Z \to b\bar{b}$ (heavy scalars, large tan) and (m_chi ~ M_Z/2)



Neutralino – SUSY dark matter

$$\chi\chi \to A \to b\bar{b} \to X, \gamma, e^{+}, \bar{p}$$

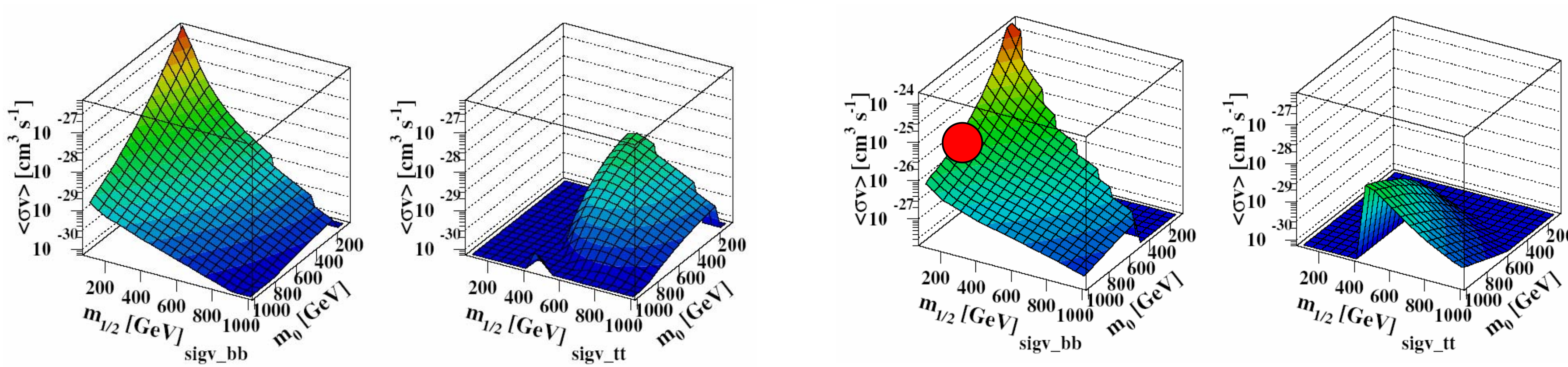
- B-fragmentation well studied at LEP! Yield and spectra of positrons, gammas and antiprotons well known!
- Galaxy = SUPER-B-factory with luminosity some 40 orders of magnitude above man-made B-factories



Neutralino – SUSY dark matter

- Annihilation cross sections in m_0-$m_{1/2}$ plane ($\mu > 0$, $A_0=0$)

tanβ=5 tanβ=50

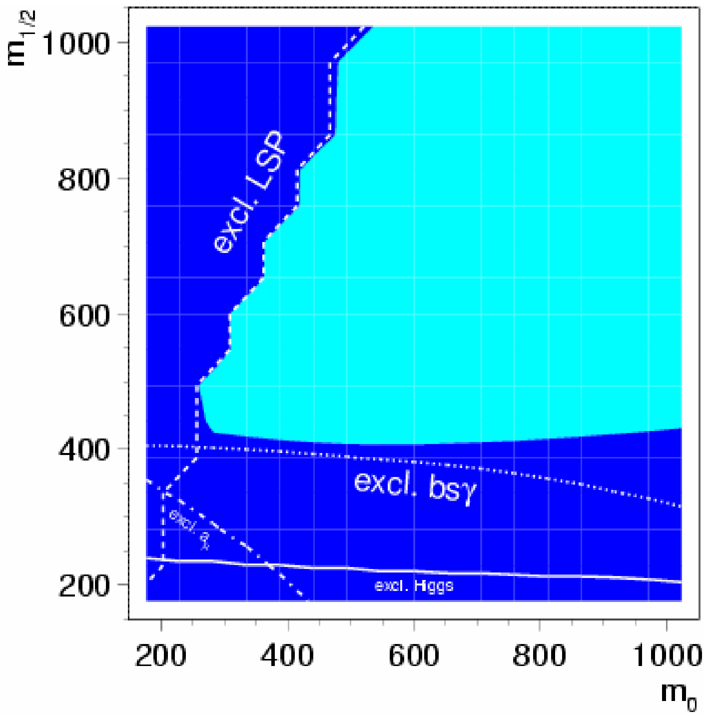


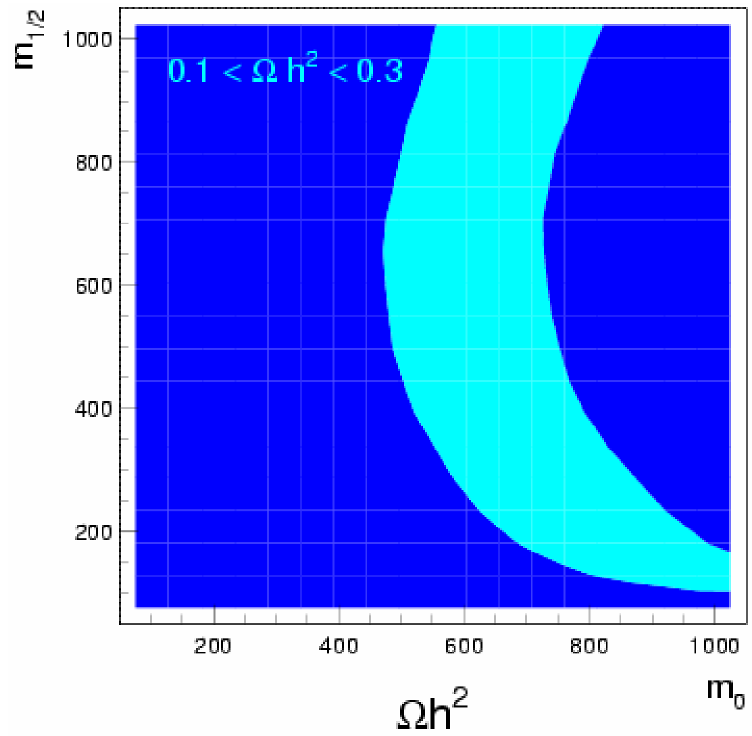
$b\bar{b}$ $t\,\bar{t}$ $b\bar{b}$ $t\,\bar{t}$

- For WMAP cross section of $\langle\sigma v\rangle \cong 2\times10^{-26}$ cm^3/s one needs large tanβ

Favoured regions of parameter space

- Pre-WMAP allowed regions in the parameter space.

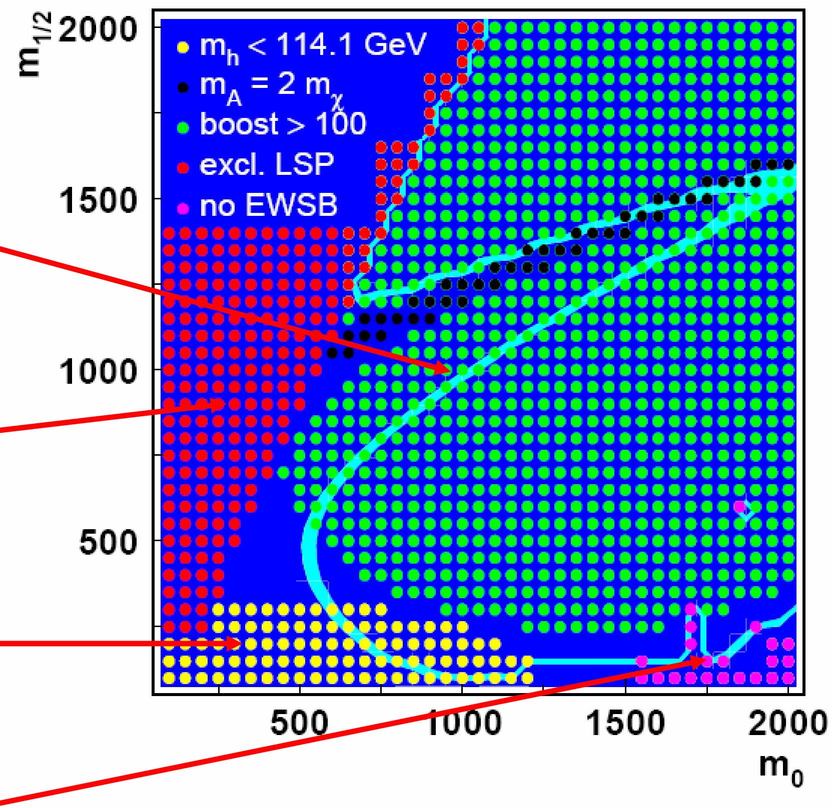




Fit to all constraints $\tan\beta=50$ Fit to Dark matter constraint

Favoured regions of parameter space

- WMAP data leave only very small allowed region as shown by the thin blue line which give acceptable neutralino relic density
- Excluded by LSP
- Excluded by Higgs searches at LEP2
- Excluded by REWSB



Favoured regions of parameter space

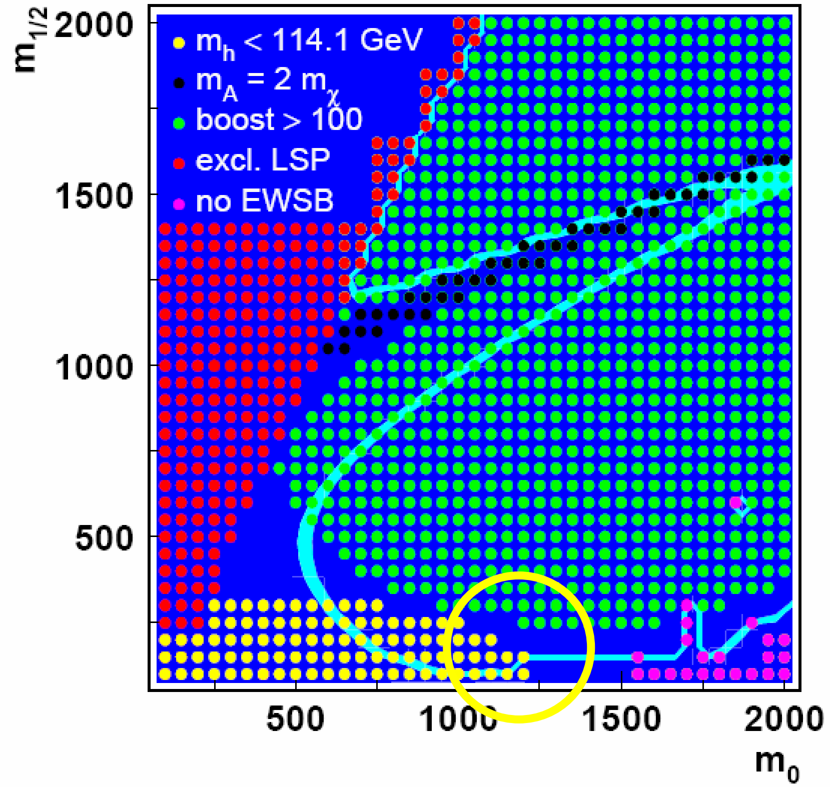
- The region compatible with all electroweak constraints as well as with WMAP and EGRET constraints are rather small
- It corresponds to the best fit values of parameters

  $\tan\beta = 51$

  $m_0 = 1400$ GeV

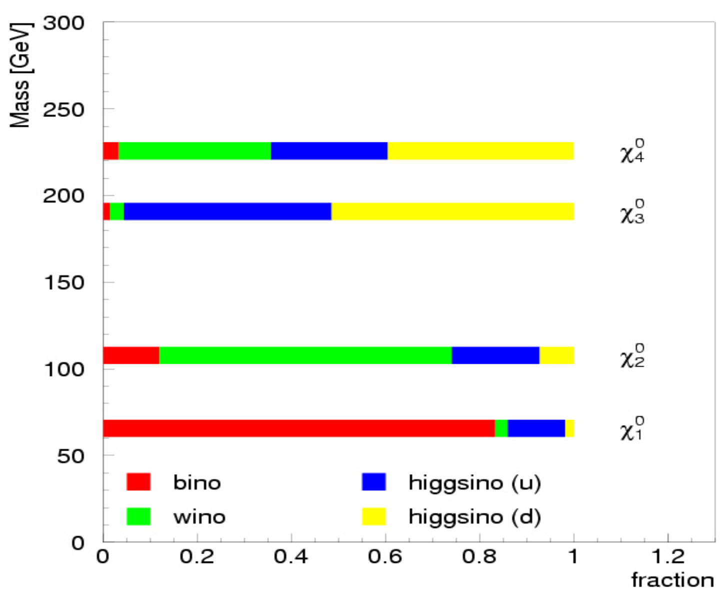
  $m_{1/2} = 180$ GeV

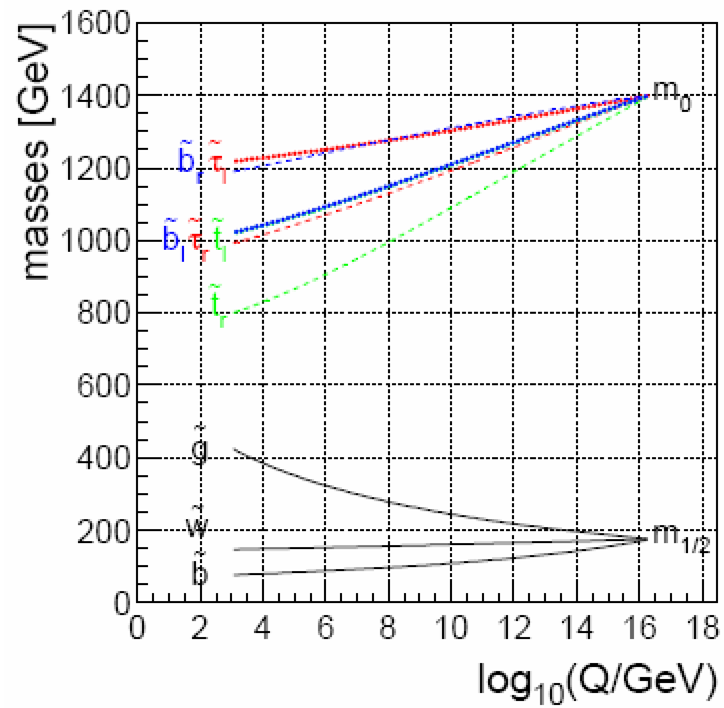
  $A_0 = 0.5\ m_0$



Favoured regions of parameter space

- Superparticle spectrum for
  m_0=1400 GeV, $m_{1/2}$=180 GeV
- Squarks/sleptons are in TeV range
- Charginos and neutralinos are light

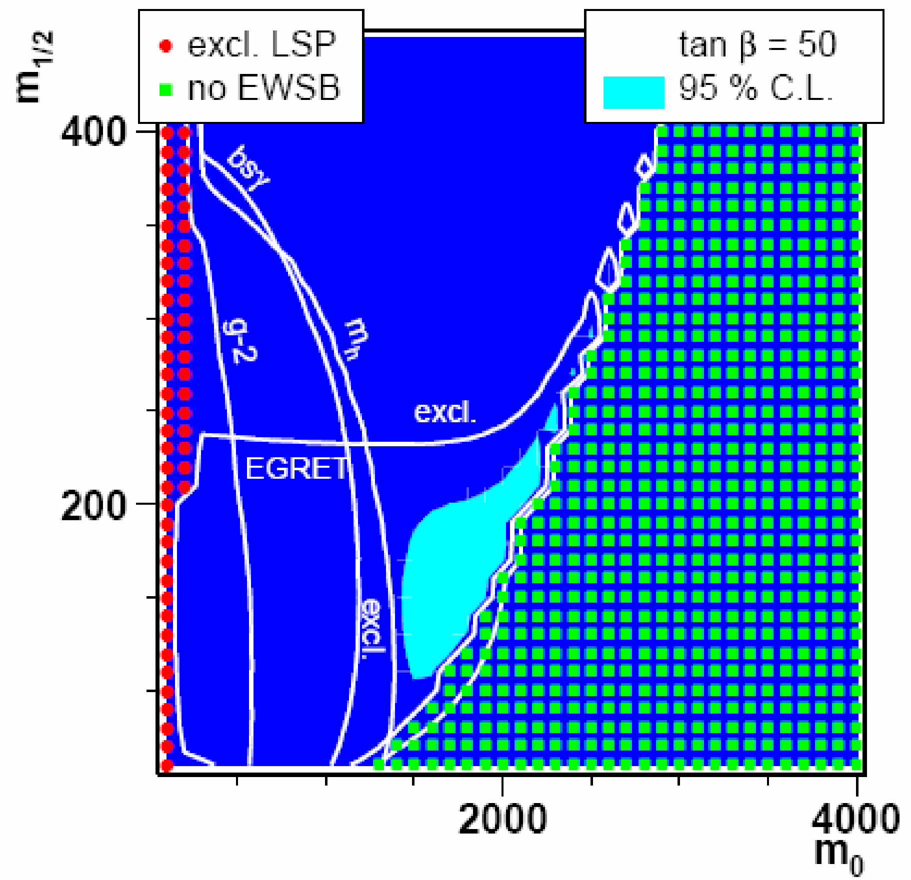




- LSP is largely Bino ⇒ Dark Matter may be supersymmetric partner of Cosmic Microwave Background

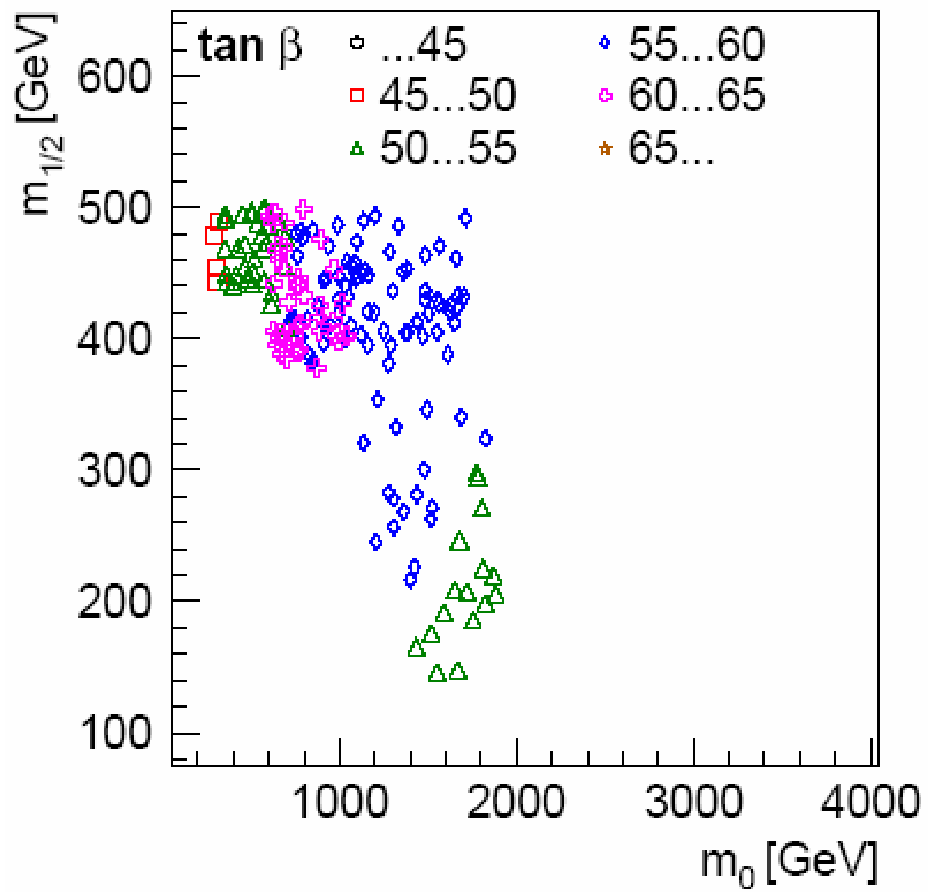
Favoured regions of parameter space

- SUSY parameter space allowed by the EGRET data and constraints by electroweak data, neutral LSP and electroweak symmetry breaking



Favoured regions of parameter space

- Results of random parameter scan with all constraints used
- Relic density constraint requires tan above 50



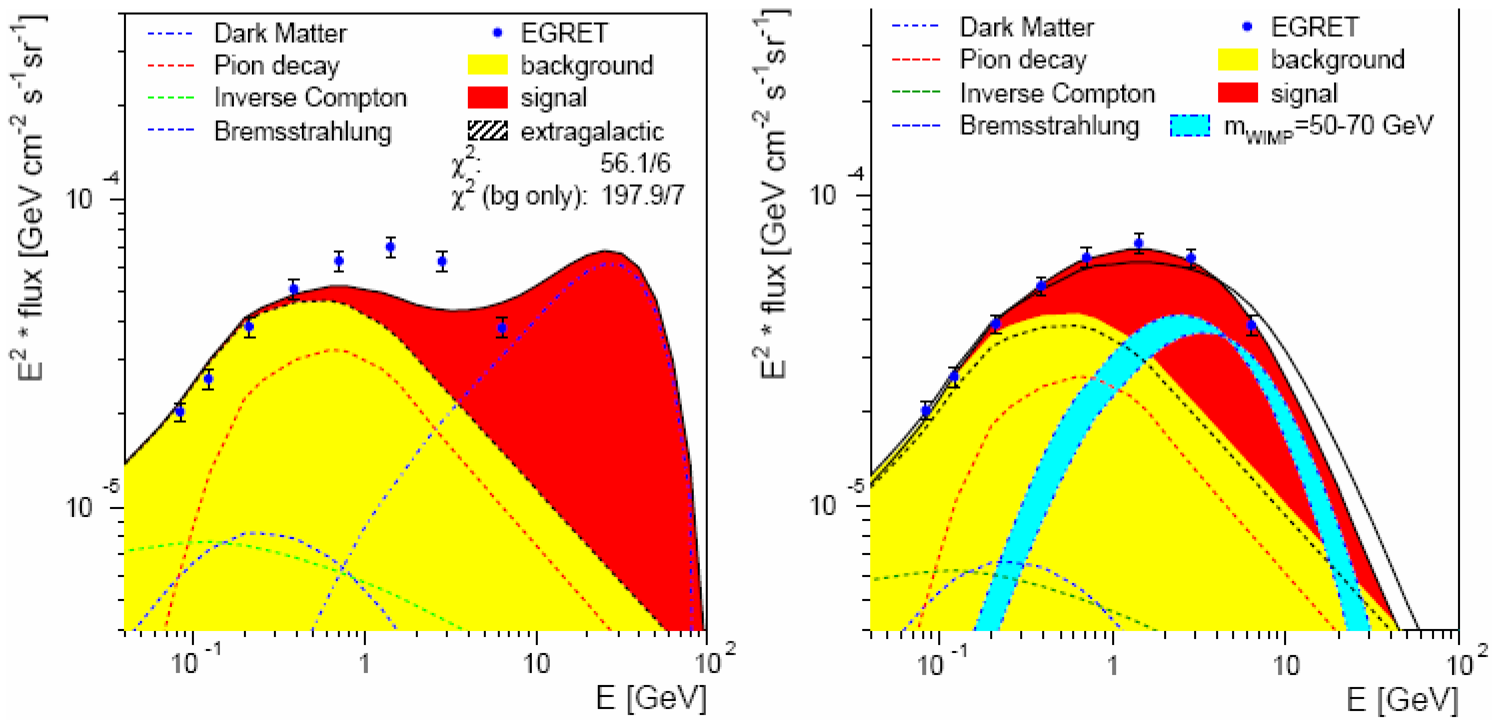
Favoured regions of parameter space

- SUSY parameters and superparticle spectrum

Parameter	Value
m_0	1500 GeV
$m_{1/2}$	170 GeV
A_0	$0 \cdot m_0$
$\tan\beta$	52.2
sign μ	$+$
$\alpha_s(M_Z)$	0.122
$\alpha_{em}(M_Z)$	0.0078153697
$1/\alpha_{em}$	127.953
$\sin^2(\theta_W)_{\overline{MS}}$	0.2314
m_t	175 GeV
m_b	4.214 GeV

Particle	Mass [GeV]
$\tilde{\chi}^0_{1,2,3,4}$	64, 113, 194, 229
$\tilde{\chi}^{\pm}_{1,2}, \tilde{g}$	110, 230, 516
$\tilde{u}_{1,2} = \tilde{c}_{1,2}$	1519, 1523
$\tilde{d}_{1,2} = \tilde{s}_{1,2}$	1522, 1524
$\tilde{t}_{1,2}$	906, 1046
$\tilde{b}_{1,2}$	1039, 1152
$\tilde{e}_{1,2} = \tilde{\mu}_{1,2}$	1497, 1499
$\tilde{\tau}_{1,2}$	1035, 1288
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	1495, 1495, 1286
$h, H, A, H^{\pm}$	115, 372, 372, 383
Observable	**Value**
$Br(b \to X_s\gamma)$	$3.02 \cdot 10^{-4}$
Δa_μ	$1.07 \cdot 10^{-9}$
Ωh^2	0.117

Favoured regions of parameter space



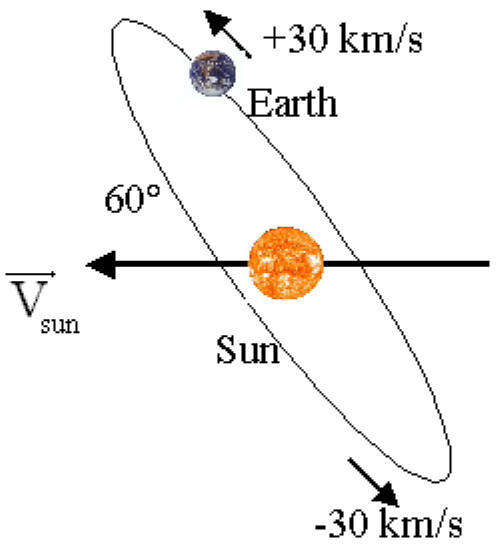
: *The EGRET gamma ray spectrum fitted with DM annihilation for* $(m_0 = 70, m_{1/2} = 250, \tan\beta = 10)$ *(left) and* $(\mathrm{m}_0 = 1400, \mathrm{m}_{1/2} = 175, \tan\beta = 51)$ *(right). In both cases the relic density corresponds to the WMAP value, but in the first case of low* m_0 *the annihilation into stau pairs dominates, while in the latter case the annihilation into b-quarks dominates.*

Direct searches for the Dark Matter

- Positive evidence for a WIMP signal could arise from the kinematics of the Earth withing non-rotating WIMP halo.

  The sun is orbiting about the galactic centre with a velocity of ~ 220 km/s.

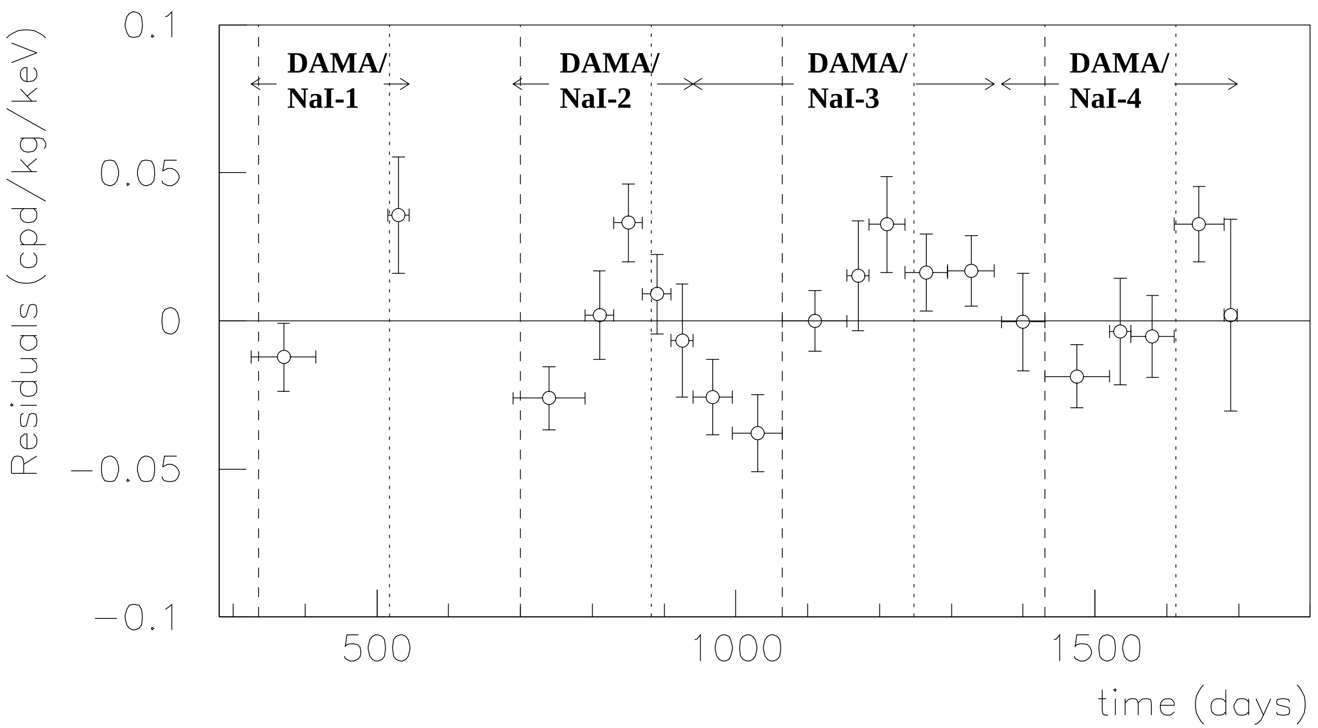
  The Earth is orbiting about the Sun with a velocity of ~ 30 km/s.



- The resulting relative Earth-halo velocity is modulated, thus the WIMP flux is also modulated which should lead to the modulation of the count rate.

Direct searches for the Dark Matter

- DAMA group claim they do observe the modulation of their count rate (results of 4 years running - 57986 kg·d)



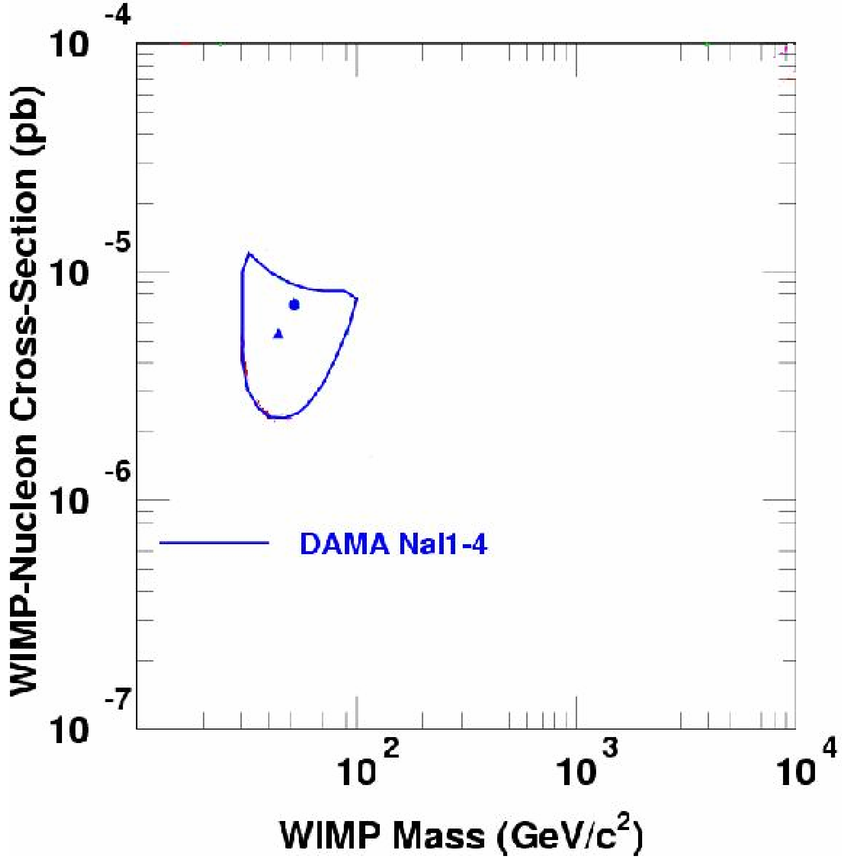
Direct searches for the Dark Matter

- This result is compatible with a signal from WIMPs with a mass

$$m_{WIMP} = 52^{+10}_{-8}\ GeV$$

and a WIMP-nucleon cross section of

$$\sigma = 7.2^{+0.4}_{-0.9} \times 10^{-6}\,\text{pb}$$

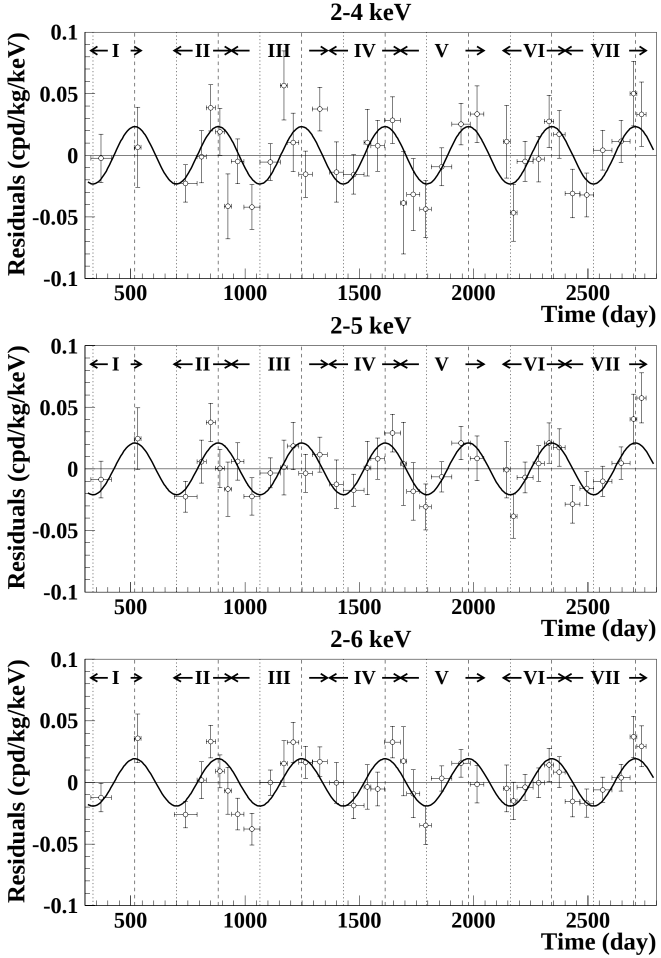


Direct searches for the Dark Matter

- Severe criticism has arisen in the community, ascribing the observed annual modulation rater to systematics than to a WIMP signature.

DAMA insists on their analysis:

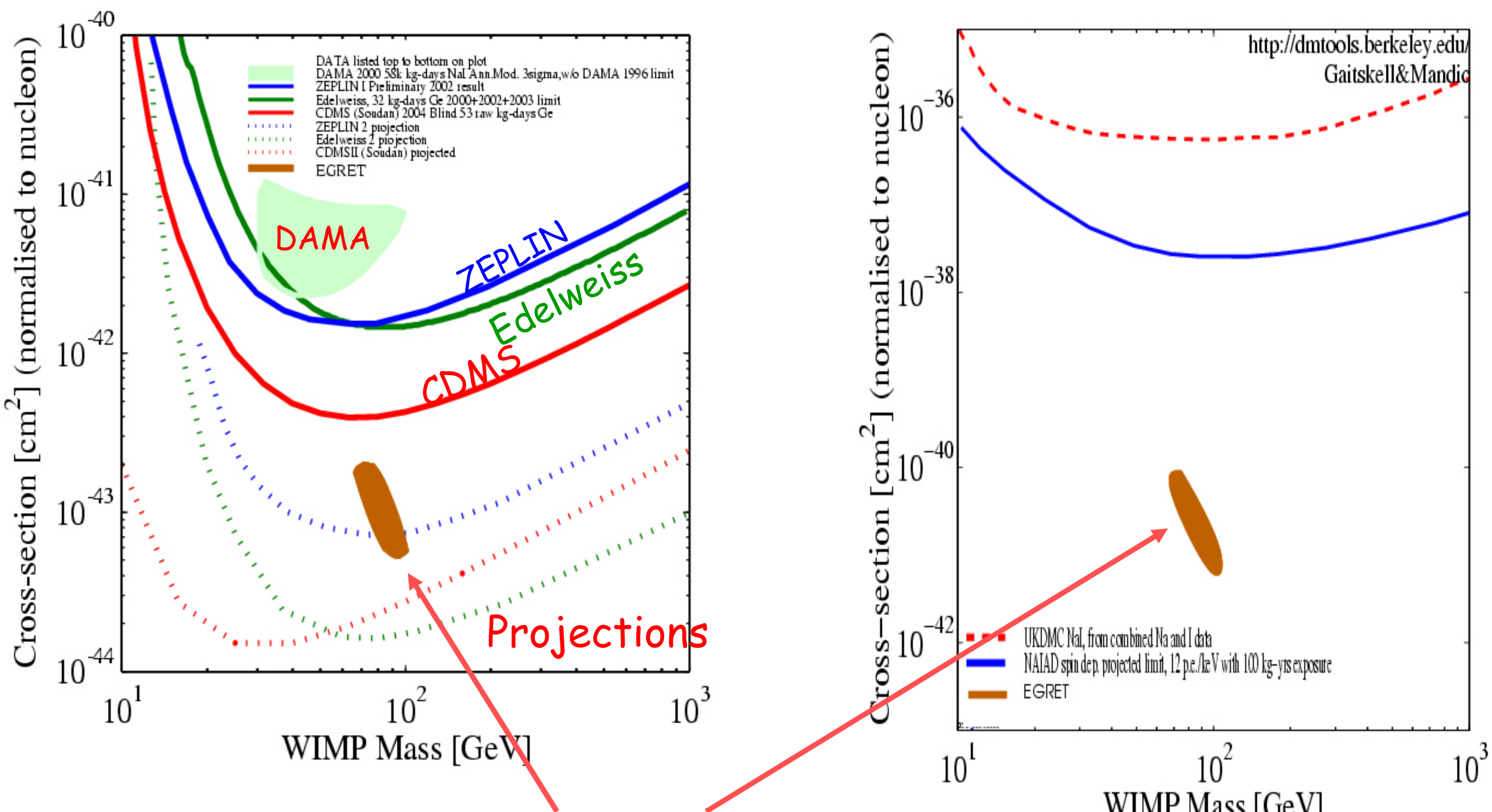
- presence of annual modulation with the proper features;
- neither systematics nor side reactions able to mimic the signature



Comparison with direct DM searches

Spin-independent

Spin-dependent



Prediction from EGRET data assuming supersymmetry

Summary: input

- Astronomy
  - Dark matter in clusters of galaxies and galaxies itself
  - Rotation curve of the Milky Way
- Astrophysics
  - Gamma ray flux from the sky (EGRET)
  - Positrons and antiprotons in cosmic rays
- Cosmology
  - Amount of the dark matter (~23%)
- Particle physics
  - Annihilation cross sections
  - Spectrum of gamma quanta from quarks/antiquarks

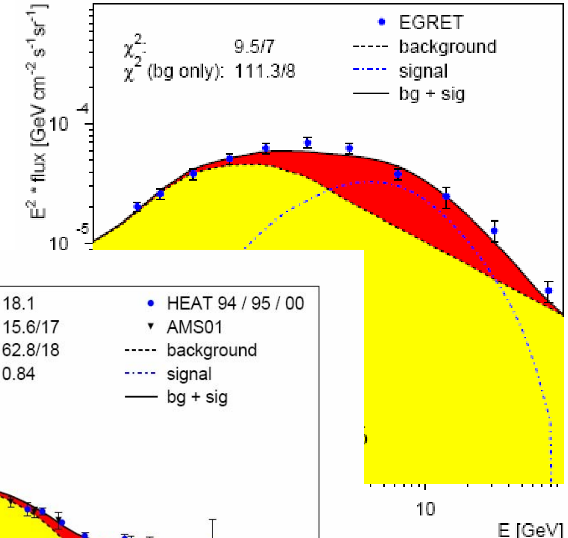
Summary: physics questions & answers

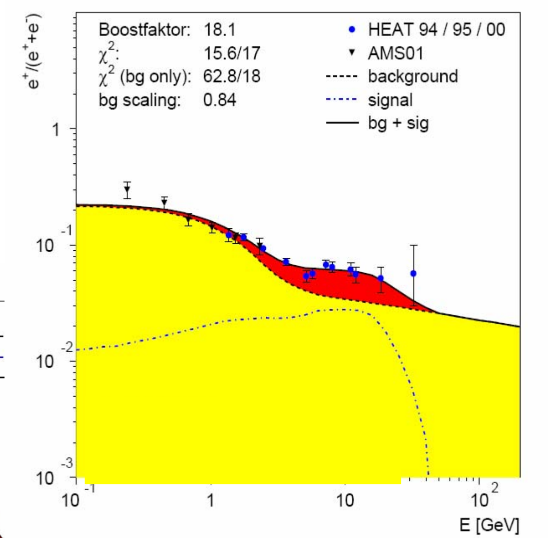
- Astrophysicists:

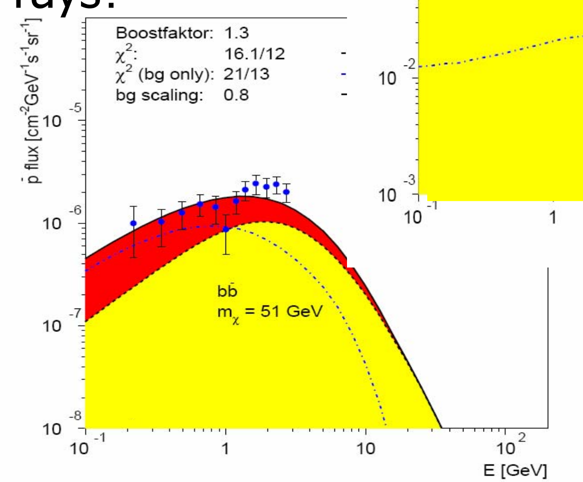
  What is the origin of “GeV excess” of diffuse galactic gamma rays?

  What is the origin of “7 GeV excess” of positrons in cosmic rays?

  What is the origin of “GeV excess” of antiprotons in cosmic rays?







Answer:
Dark matter annihilation

Summary: physics questions & answers

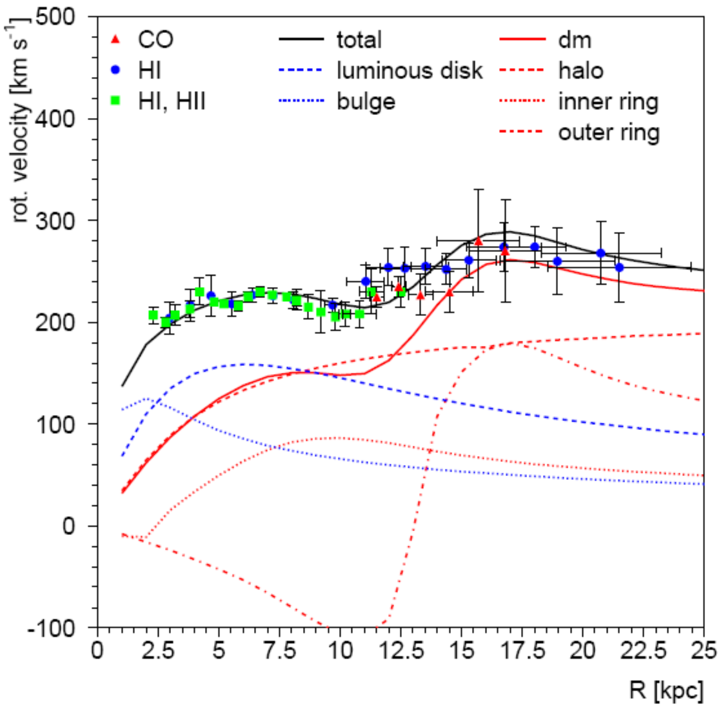
- Astronomers:

Why a change of slope in the Milky Way rotation curve at R_0=8.3 kpc?

Answer: Dark matter substructure

Why ring of stars at 14 kpc so stable?

Why ring of molecular hydrogen at 4 kpc so stable?

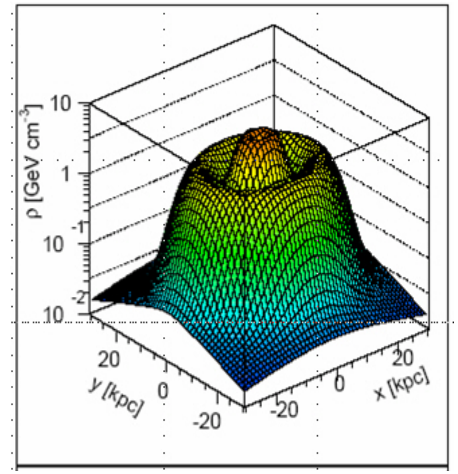


Summary: physics questions & answers

- Cosmologists:

  How is Cold Dark Matter distributed?

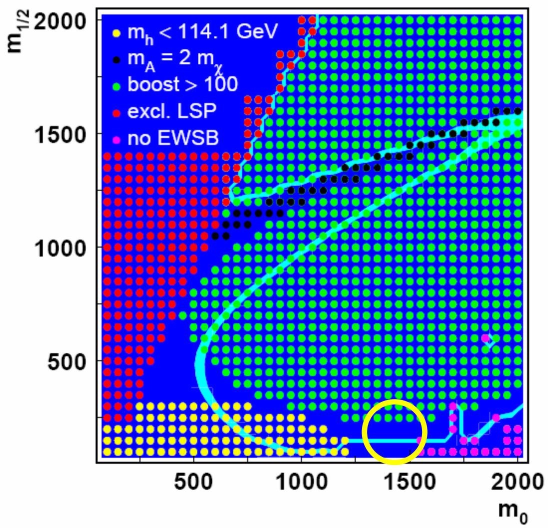
  Answer: $1/r^2$ profile + substructure (two rings)



- Particle physicists:

  Is DM annihilating as expected in Supersymmetry?

  Answer: Cross sections are perfectly consistent with SUSY

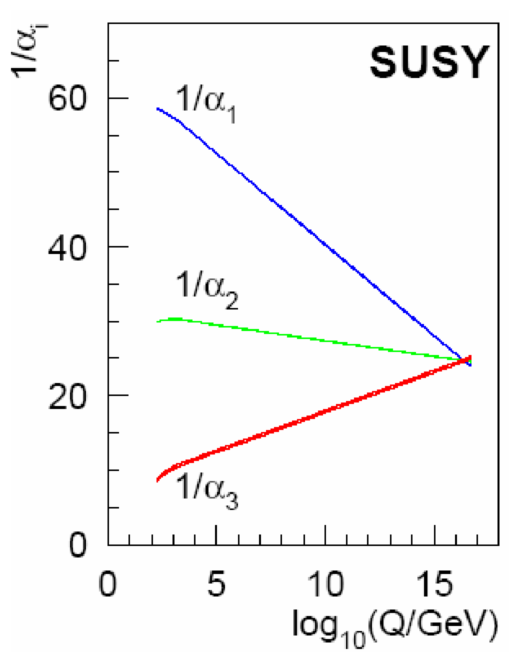


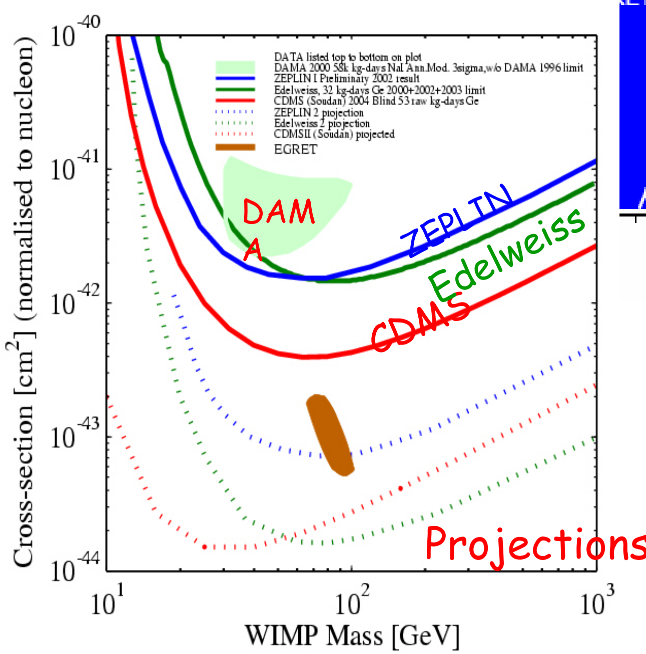
Summary: physics questions & answers

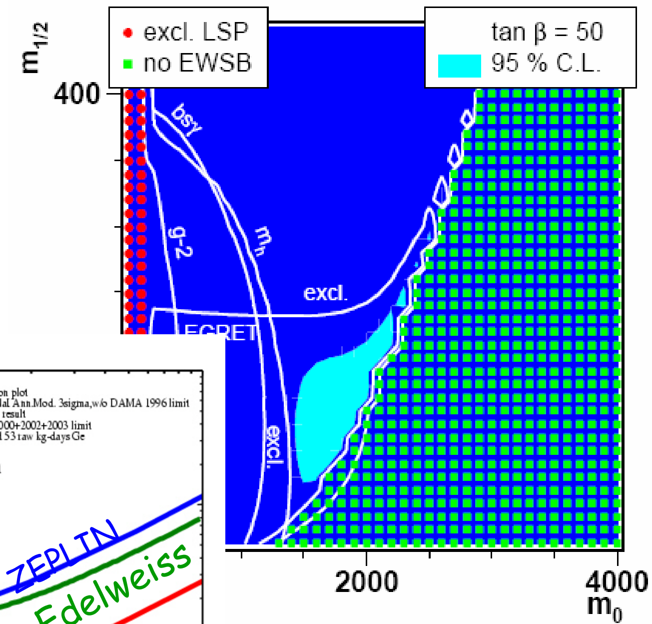
- Particle physicists:

  New interesting phenomenology

  EGRET constraint is consistent with GUT and direct DM searches







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