Dark Matter not so dark anymore?

- What is known about Dark Matter?

  23% of the Energy of the Universe
  Weakly interacting Massive Partice (WIMP)
  Annihilation with $<\sigma v>=2.10^{-26}$ cm^3/s

- Annihilation into Quarkpairs ->
  Excess in galactic Gamma rays (π_0 decays)
  Indeed observed by EGRET satellite

- WIMP Mass 50-100 GeV from spectrum

- Halo distribution of DM by observing in many sky directions

- Data consistent with Supersymmetry

From CMB + SN1a + surveys

if it is not dark,
it does not matter

Ingredients to analysis

Astronomy

Rotation curve
“Doughnut” of stars at 14 kpc
“Doughnut” of dust and H_2 at 4 kpc

Astroparticlephysics

Cosmic rays
(Gamma rays)

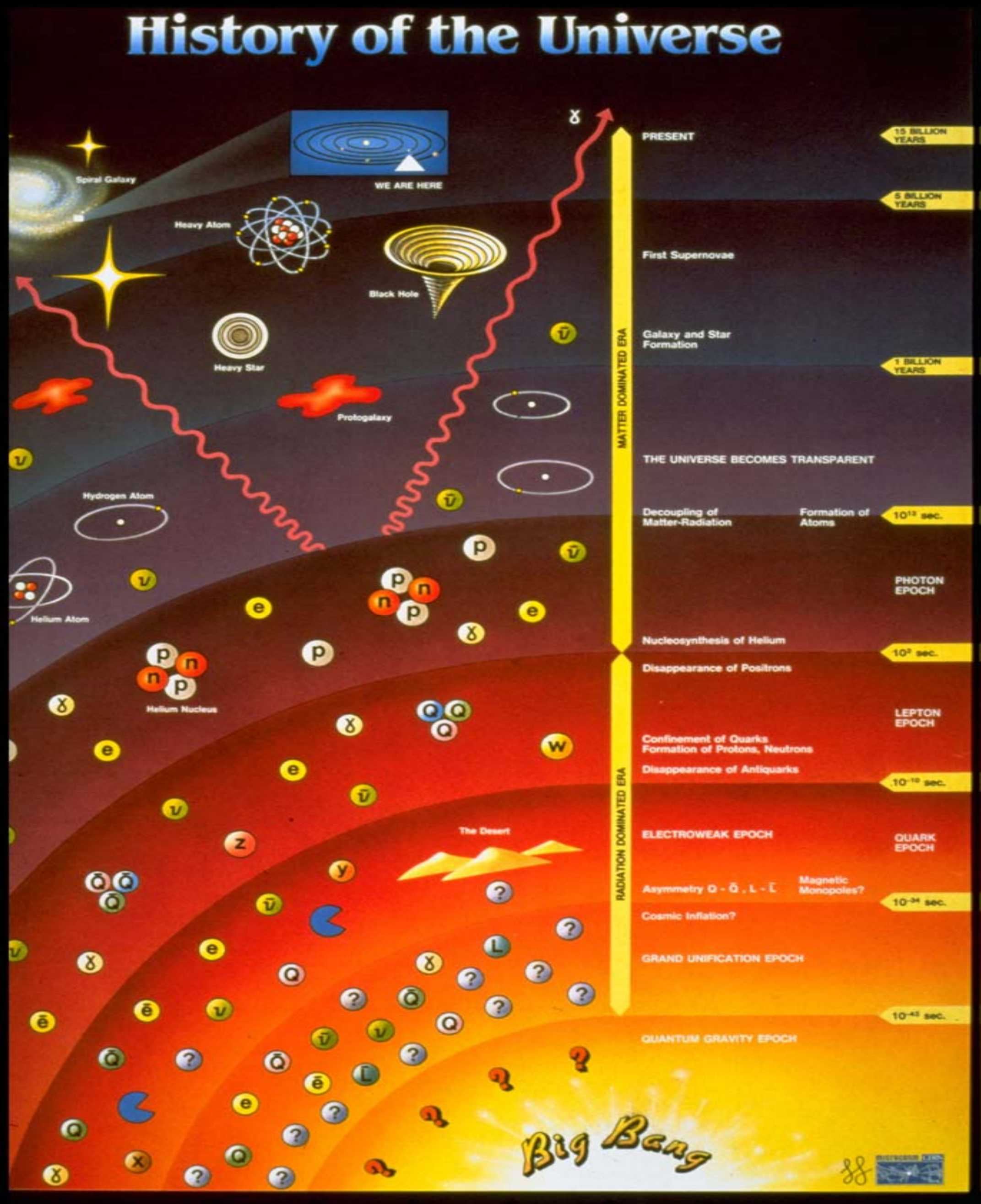
Cosmology

23%DM, Hubble->
DM Annih. x-sect.
Structure formation

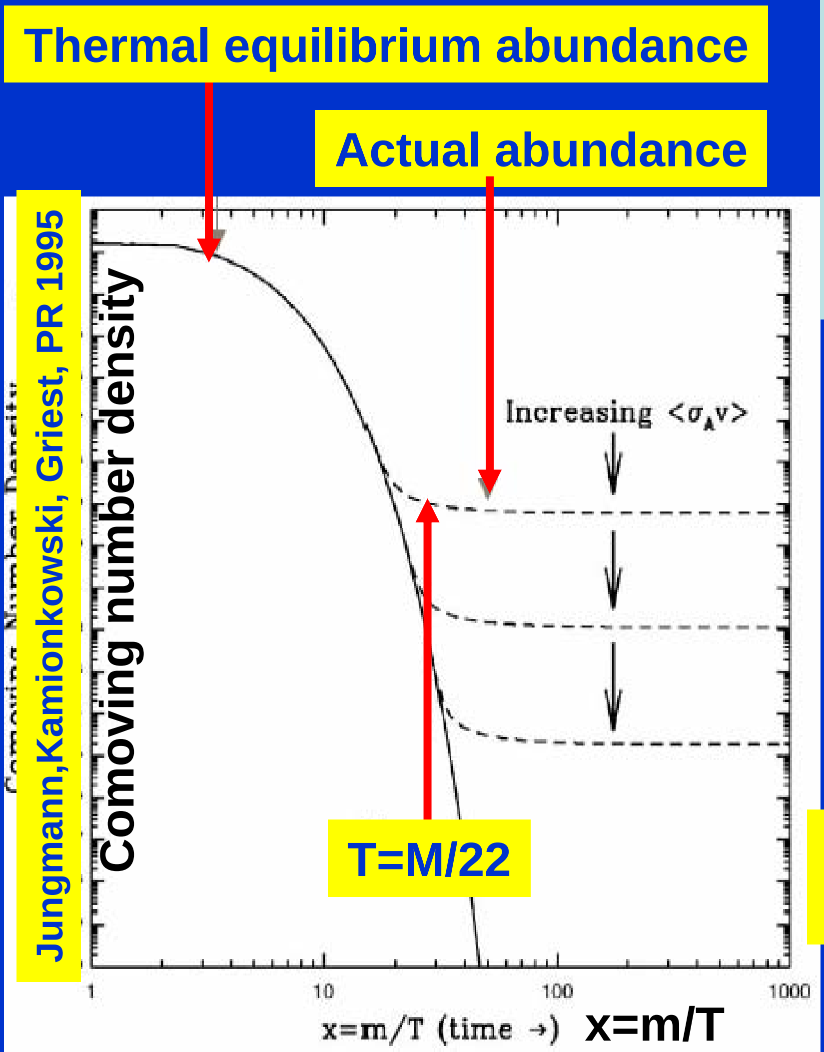
Particle Physics

Gamma spectra of background and DM Annihilation

Big Bang →



Expansion rate of universe determines WIMP annihilation cross section



T>>M: $f+\bar{f} \to M+\bar{M}$; $M+\bar{M} \to f+\bar{f}$

T<M: $M+\bar{M} \to f+\bar{f}$

T=M/22: M **decoupled**, stable density

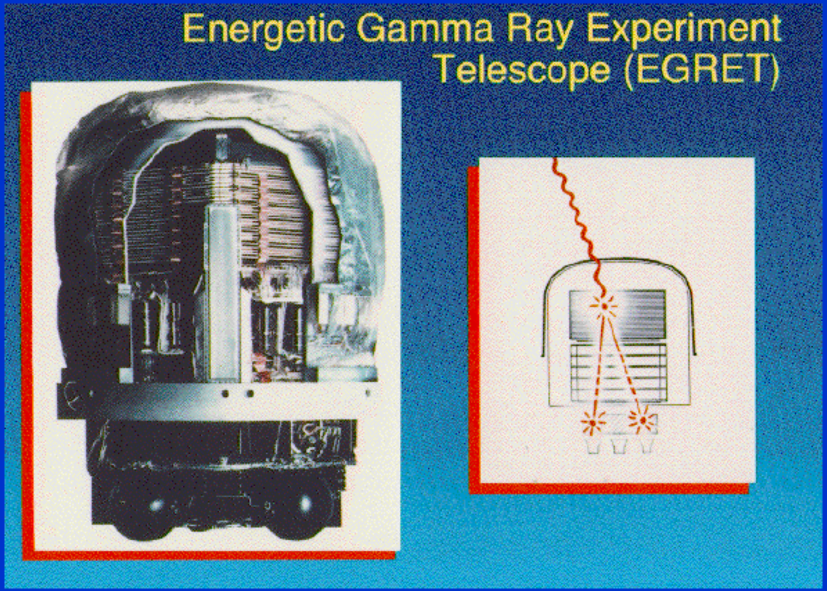
(**wenn Annihilation-rate ≅ Expansions-rate**, i.e. $\Gamma = \langle\sigma v\rangle n_\chi(x_{fr}) \cong H(x_{fr})$!)

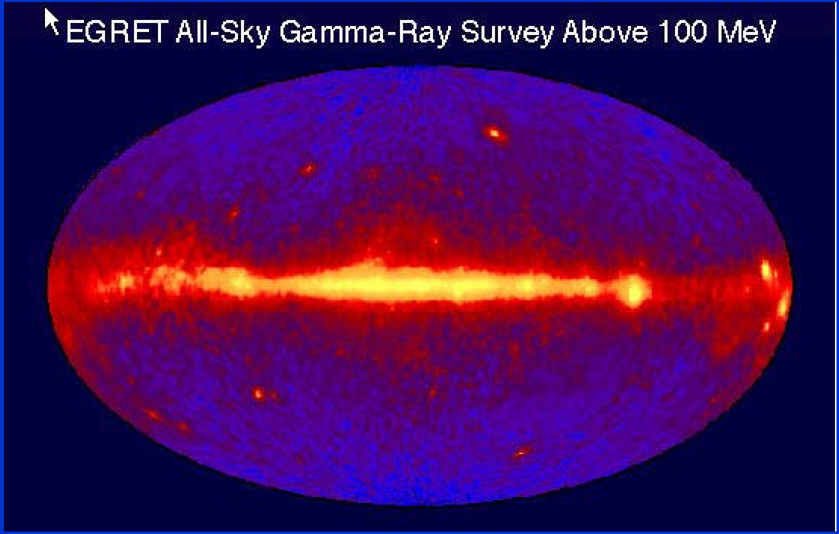
WMAP -> $\Omega h^2 = 0.113 \pm 0.009$ ->
$\langle\sigma v\rangle = 2.10^{-26}$ cm^3/s

DM increases in Galaxies:
≈1 WIMP/coffee cup ≈10^5 <ρ>.
DMA ($\propto \rho^2$) restarts again..

Annihilation into lighter particles, like Quarks and Leptons -> π_0's -> Gammas!

EGRET on CGRO (Compton Gamma Ray Observ.)



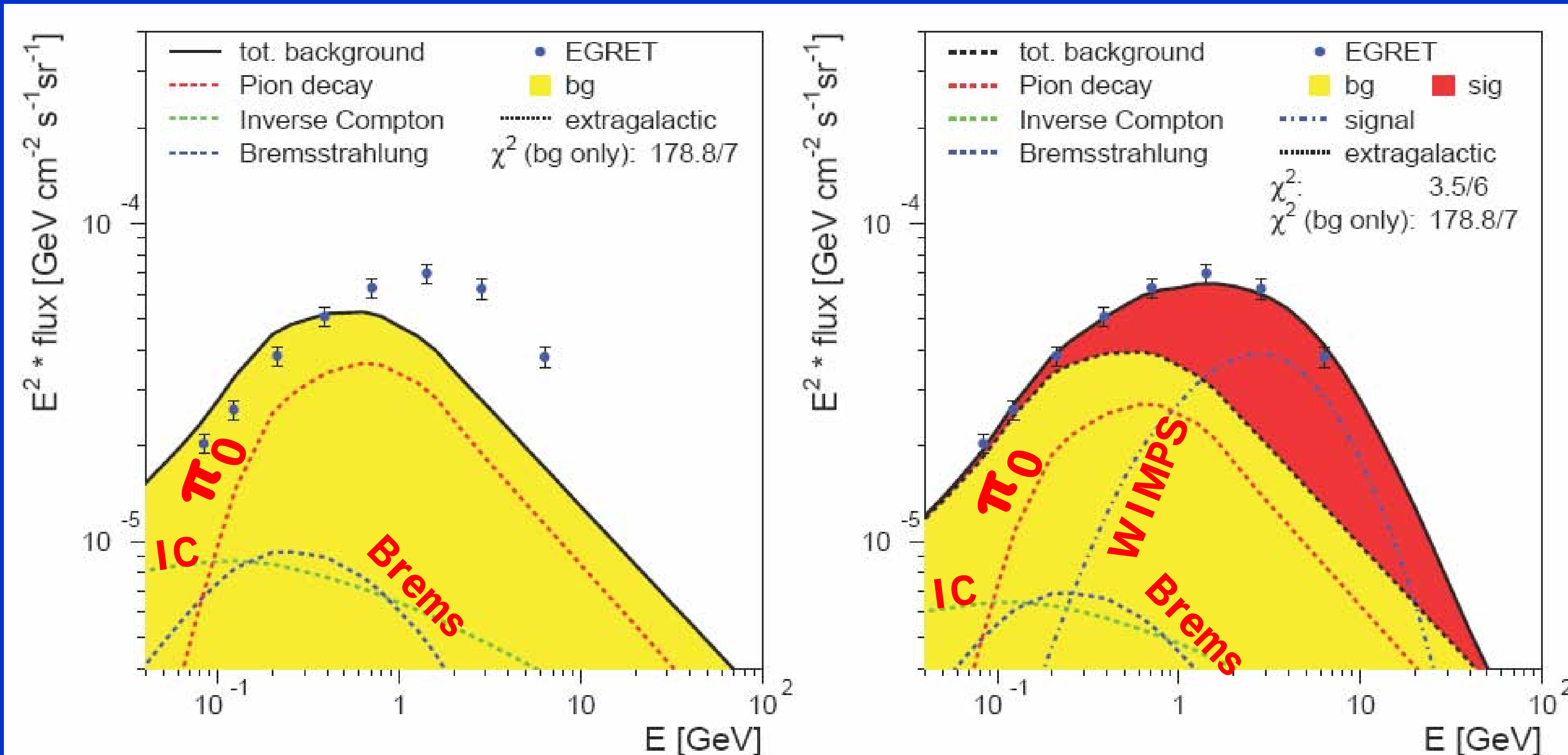


Instrument Parameters and Capabilities

1. **Type:** spark chambers, NaI(Tl) crystals, and plastic scintillators.
2. **Energy Range:** 20 MeV to about 30 GeV.
3. **Energy Resolution:** approximately twenty percent over the central part of the energy range.
4. **Total Detector Area:** approximately 6400 cm^2
5. **Effective Area:** approximately 1500 cm^2 between 200 MeV and 1000 MeV, falling at higher and lower energies.
6. **Point Source Sensitivity:** varies with the spectrum and location of the source and the observing time. Under optimum conditions, well off the galactic plane, it should be approximately 6×10^{-8} $cm^{-2}s^{-1}$ for E > 100 MeV for a full two week exposure.
7. **Source Position Location:** Varies with the nature of the source intensity, location, and energy spectrum from 5 - 30 arcmin.
8. **Field of View:** approximately a gaussian shape with a half width at half maximum of about 20. Note that the full field of view will not generally be used.
9. **Timing Accuracy:** 0.1 ms absolute
10. **Weight:** about 1830 kg (4035 lbs)
11. **Size:** 2.25 m x 1.65 m diameter
12. **Power:** 190 W (including heater power)

9 yrs of data taken in space!
(1991-2000)

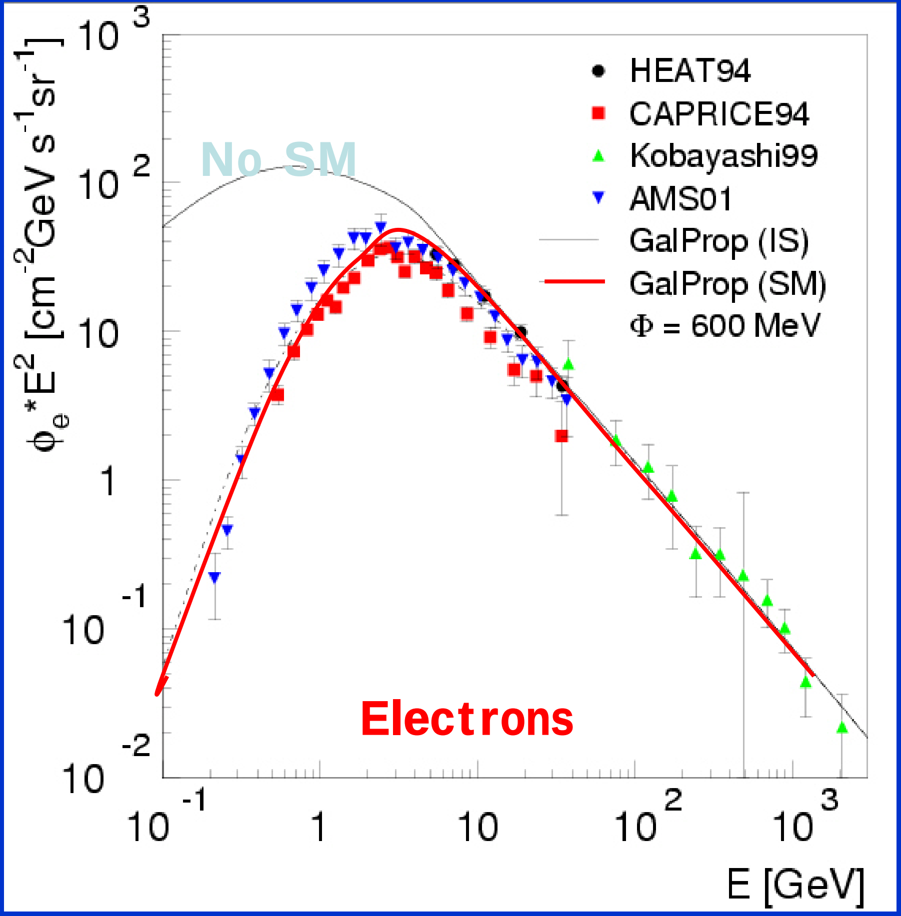
The EGRET excess of diffuse galactic gamma rays without and with DM annihilation

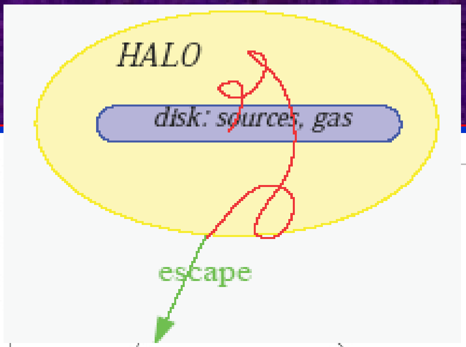


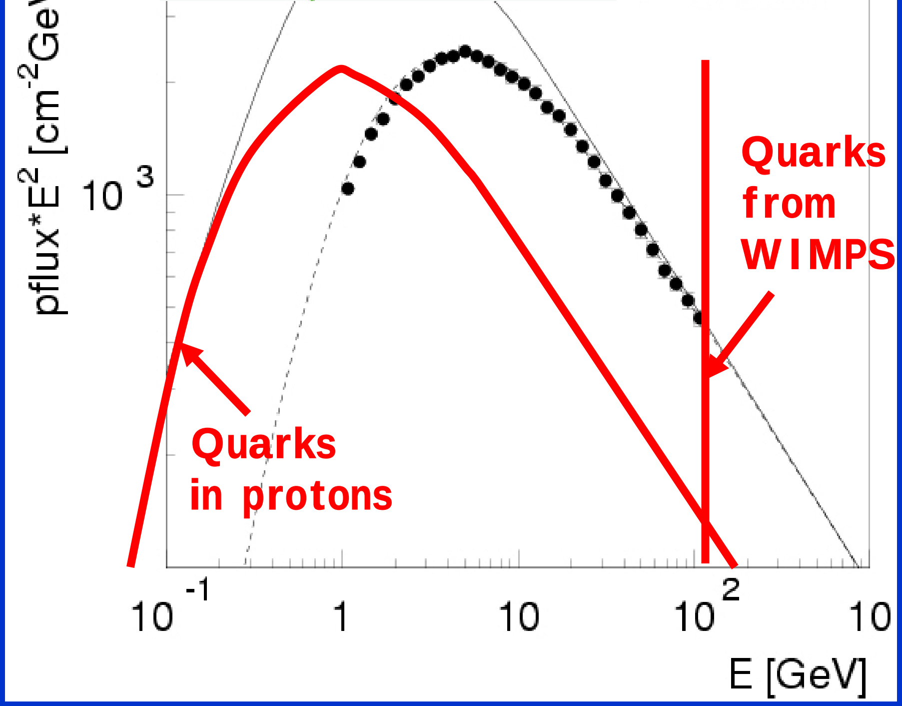
Fit only KNOWN shapes of BG + DMA, i.e. 1 or 2 parameter fit
NO GALACTIC models needed. Propagation of gammas straightforward

Gamma ray flux measured towards Galactic center

What about background shape?

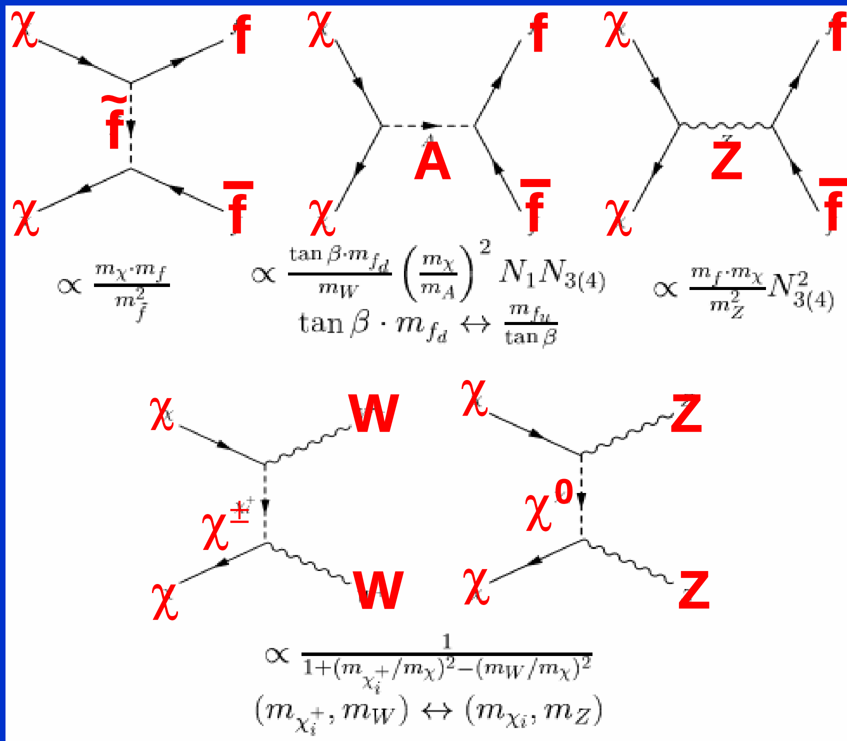


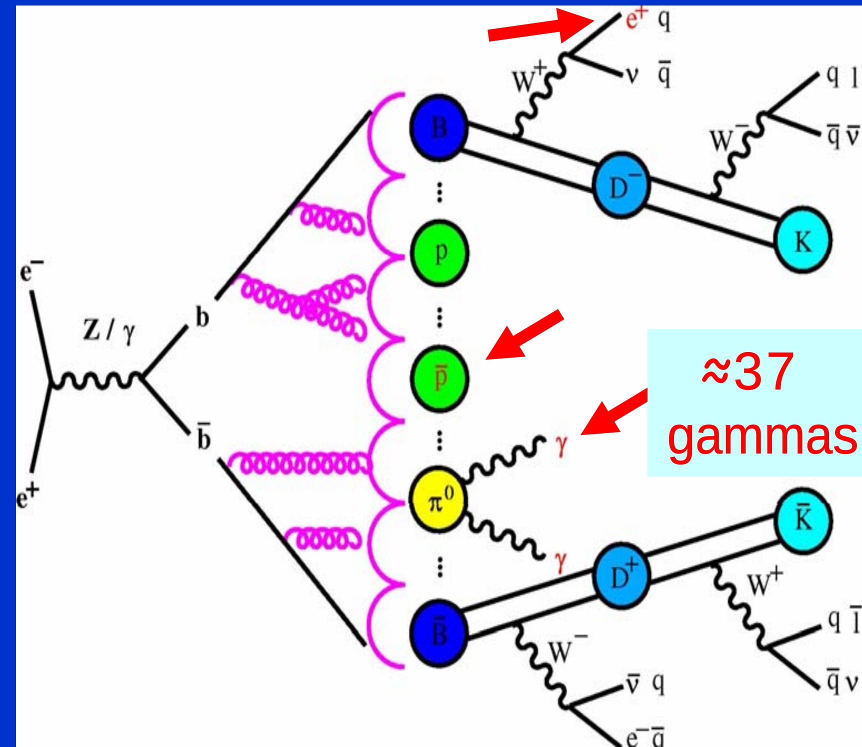




Background from nuclear interactions (mainly p+p-> π^0 + X -> γ + X
inverse Compton scattering (e-+ γ -> e- + γ)
Bremsstrahlung (e- + N -> e- + γ + N)
Shape of background KNOWN if Cosmic Ray spectra of p and e- known

What about signal shape?



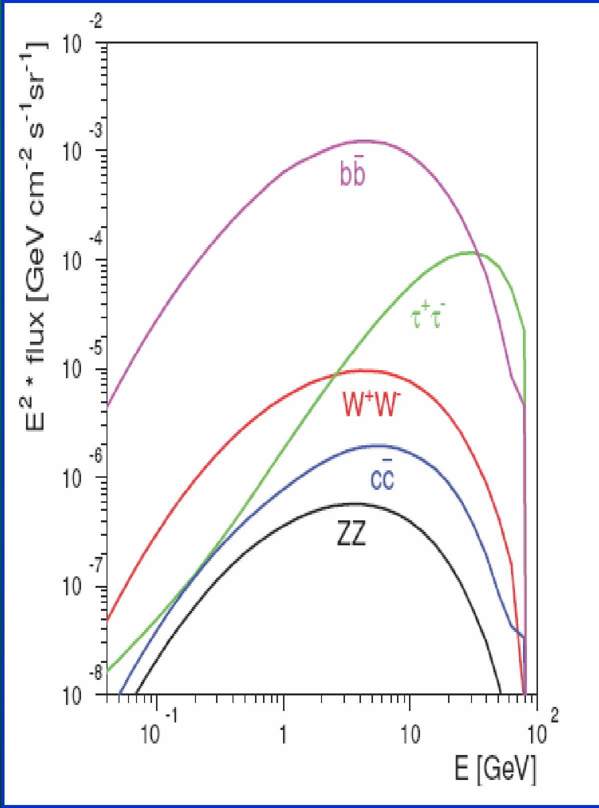


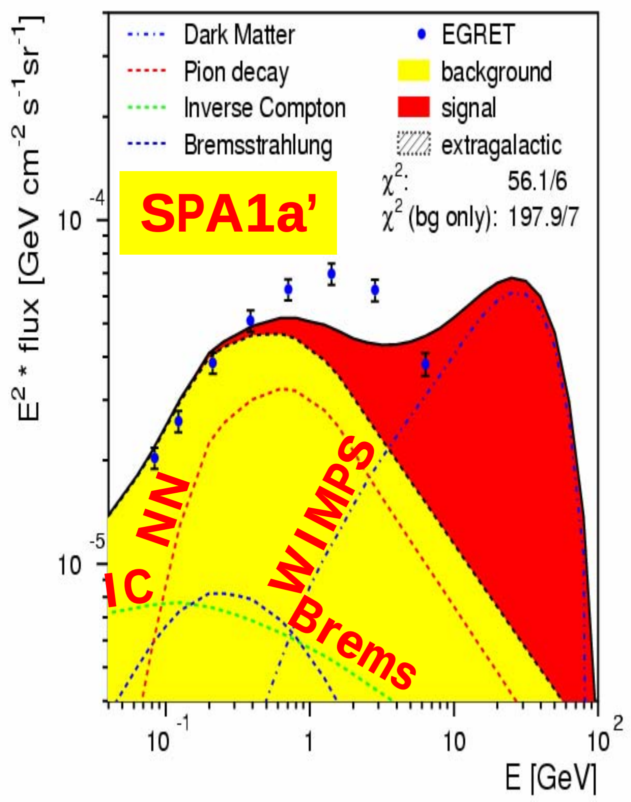
Dominant
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair

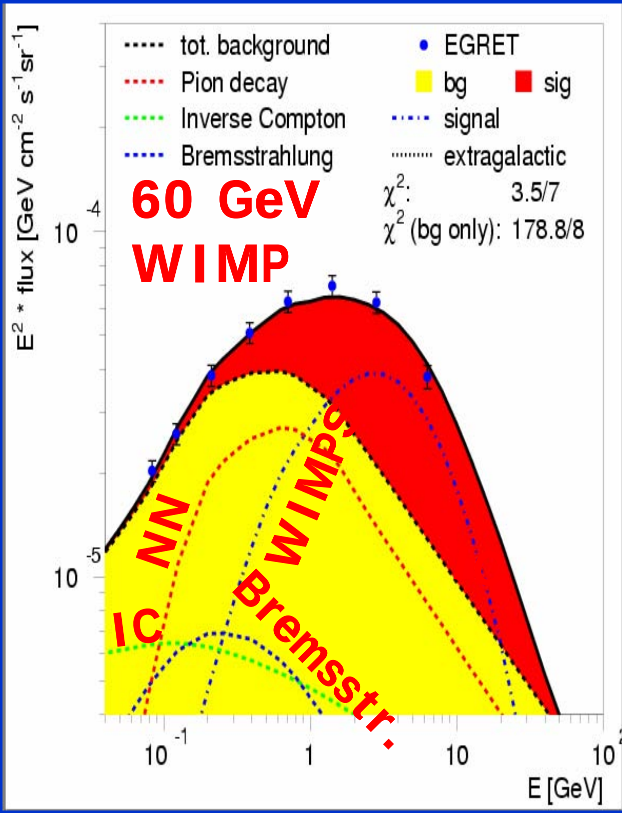
B-Fragmentation known ->
Spectra of Positrons,
Gammas and Antiprotons known!

Galaxy = Super B-Factory with rate 10^{40} x B-Factory

Gamma Spectra from WIMP Annihilation





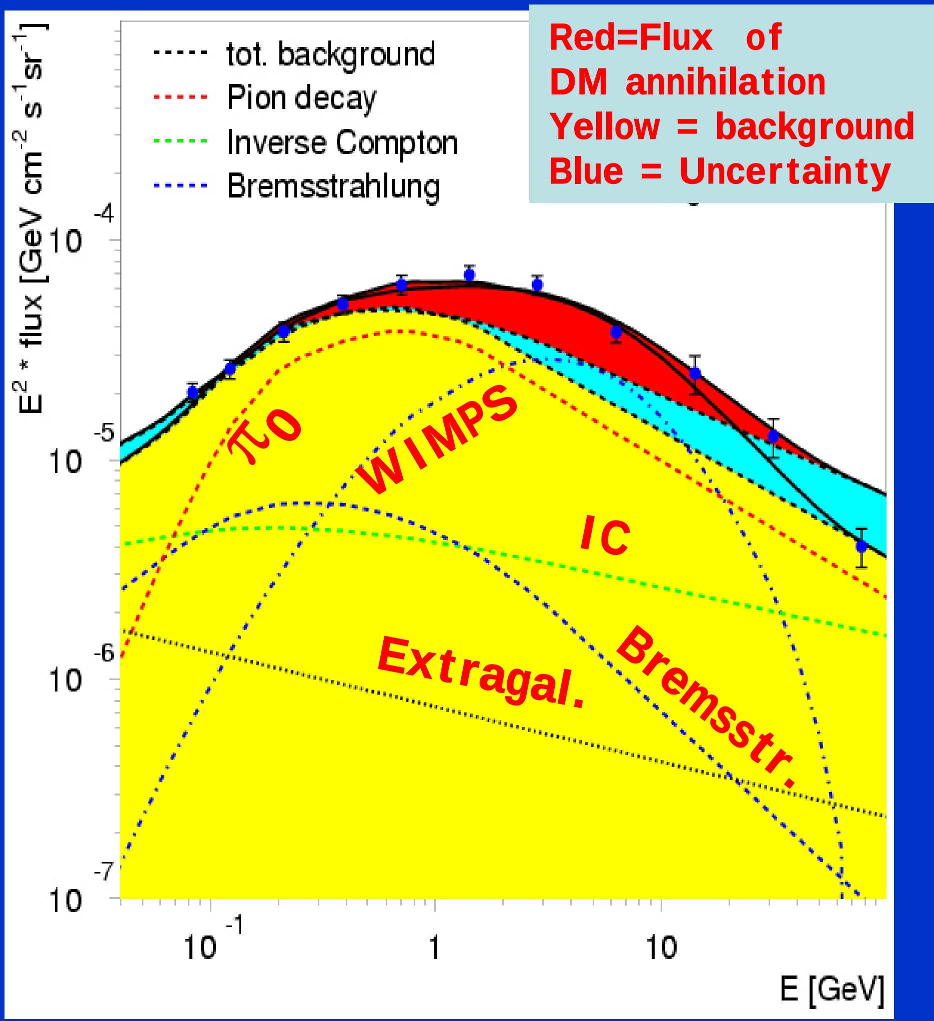


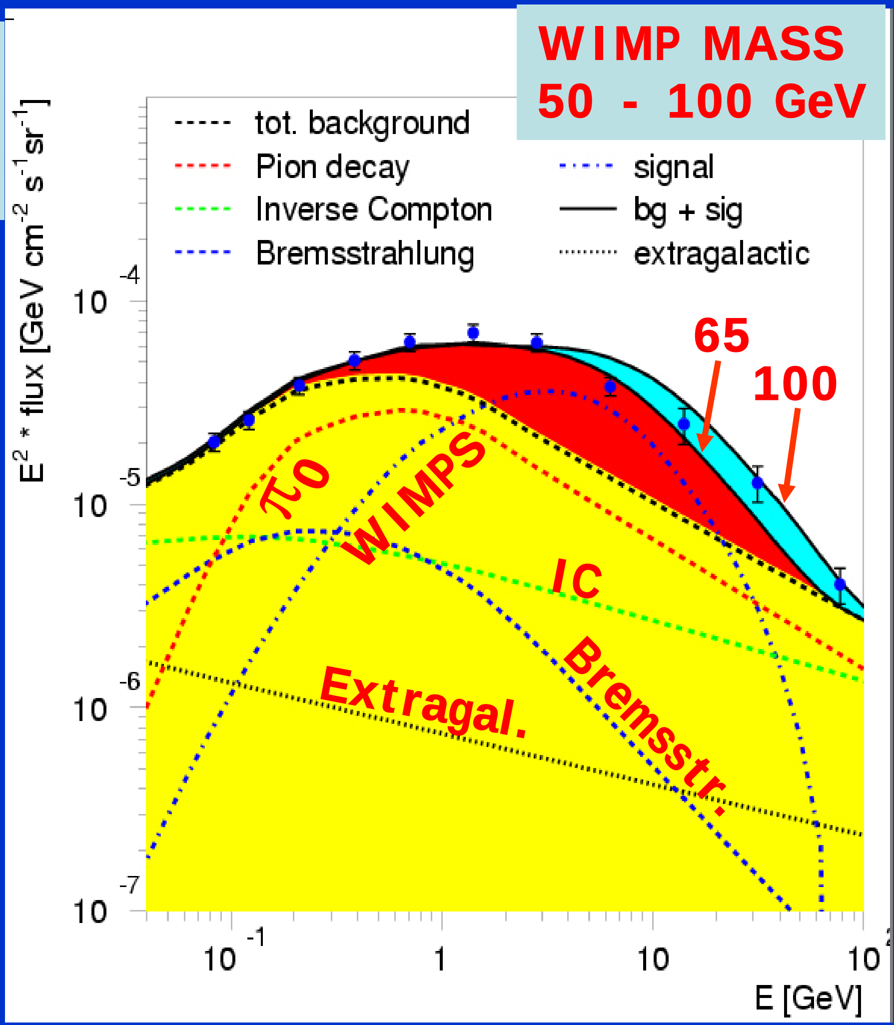
Gamma Spectra for different decay channels

Gamma Spectra with tau-decays dominant (m_0 small)

Gamma Spectra with b-fragmentation dominant (m_0 large)

Background + signal describe EGRET data!

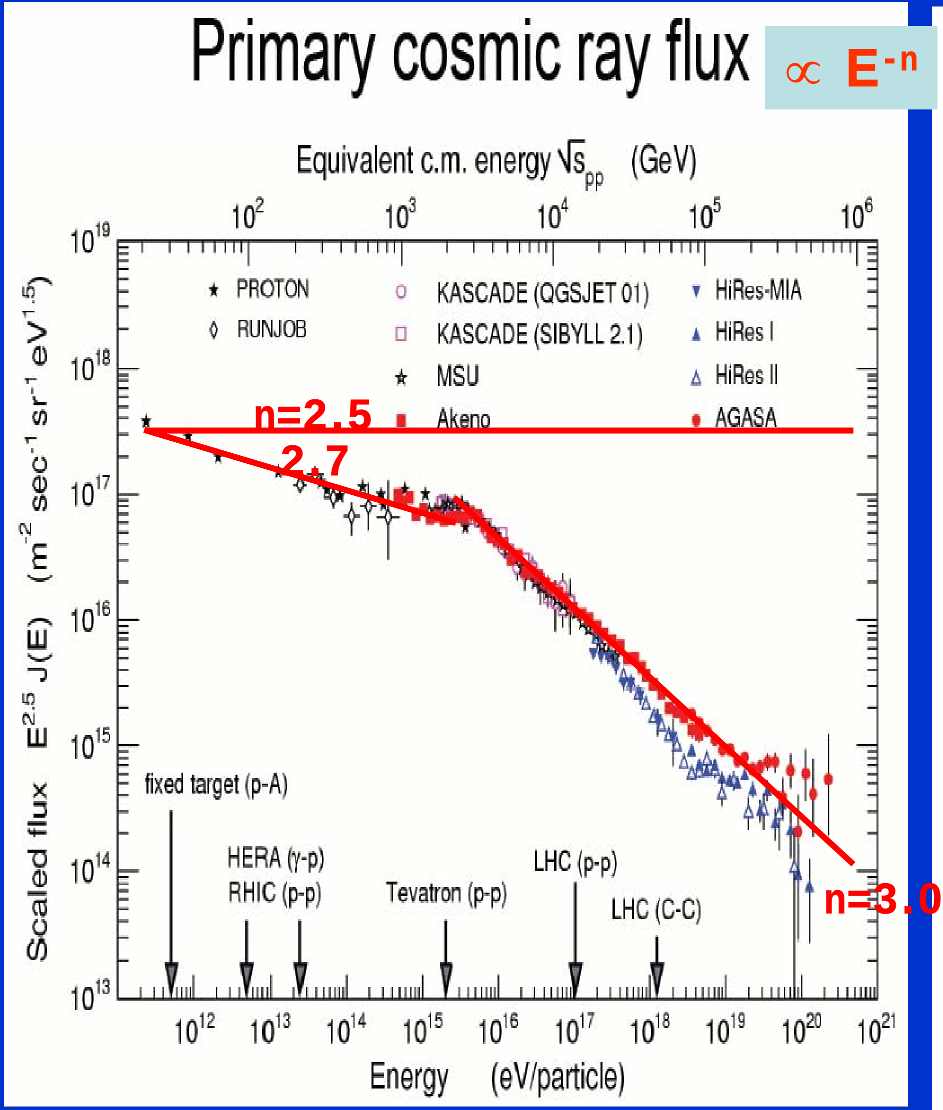


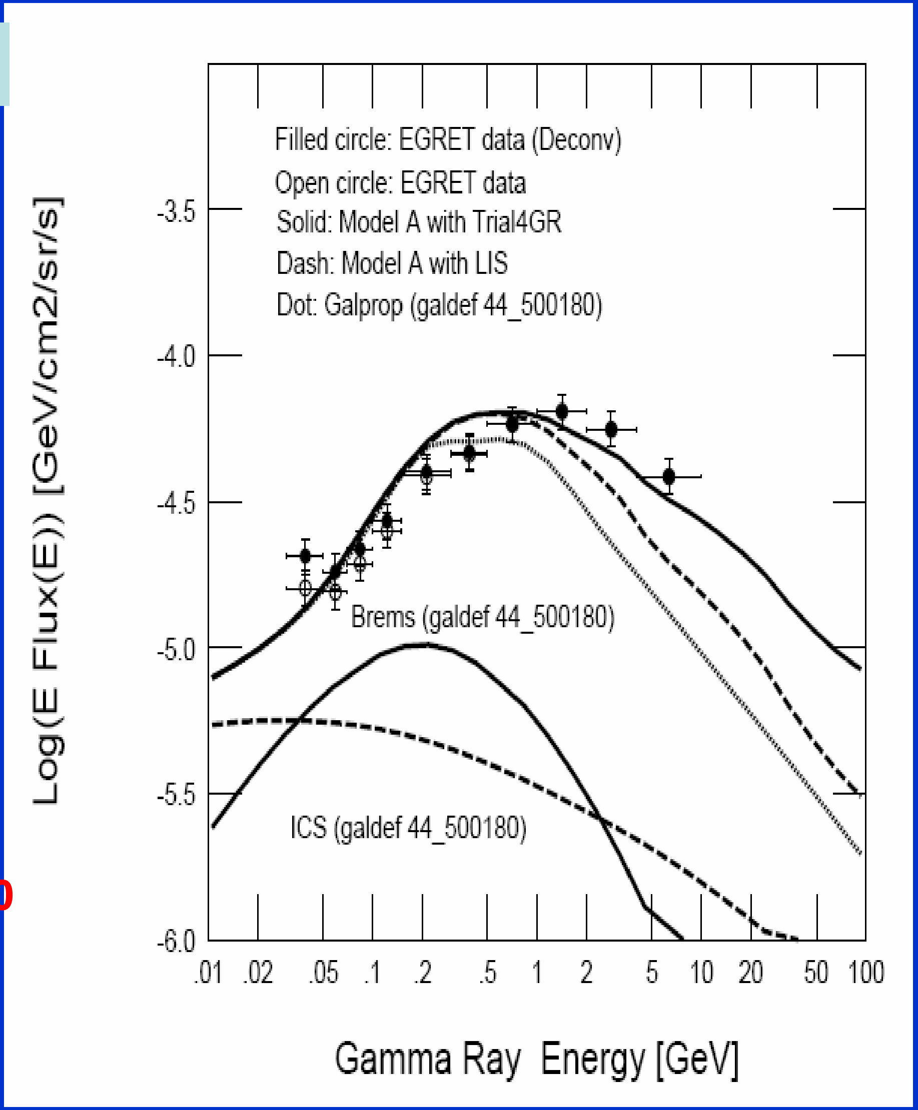


Blue: background uncertainty

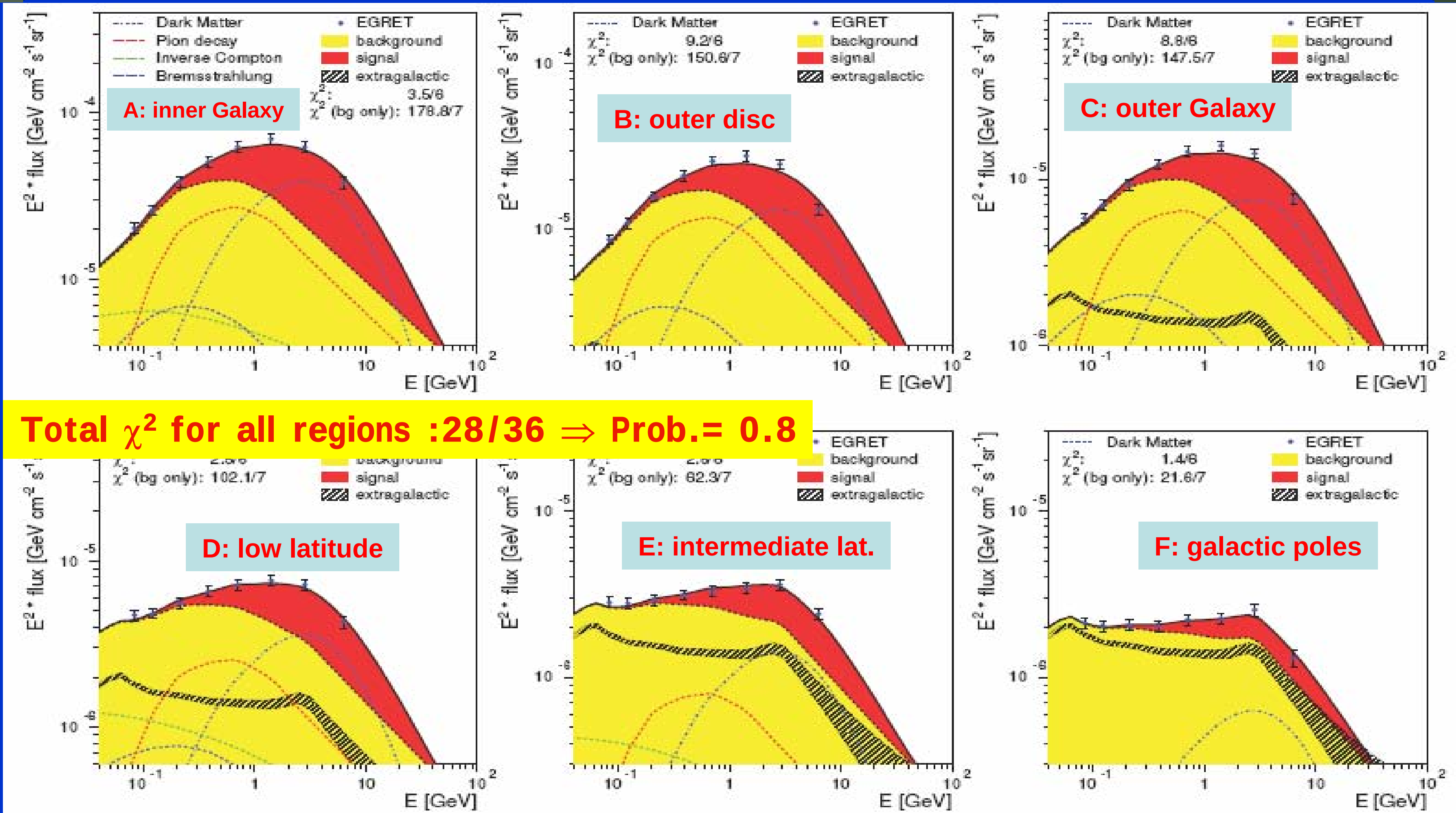
Blue: WIMP mass uncertainty

Expl. of excess by T. Kamae et al, astro-ph/0410617





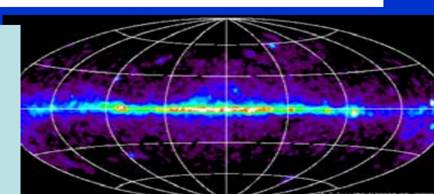
Analysis of EGRET Data in 6 sky directions



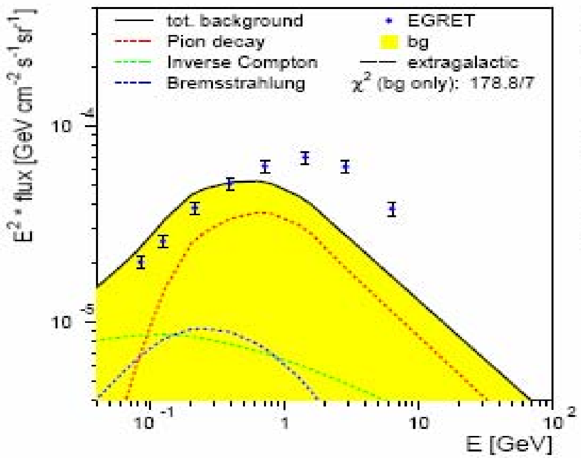
Total χ^2 for all regions :28/36 $\Rightarrow$ Prob.= 0.8

A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)
B: Galactic plane avoiding A
C: Outer Galaxy

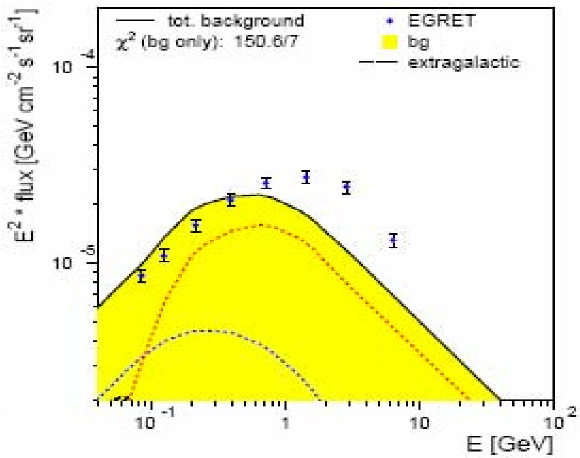
D: low latitude ($10-20^0$)
E: intermediate lat. ($20-60^0$)
F: Galactic poles ($60-90^0$)



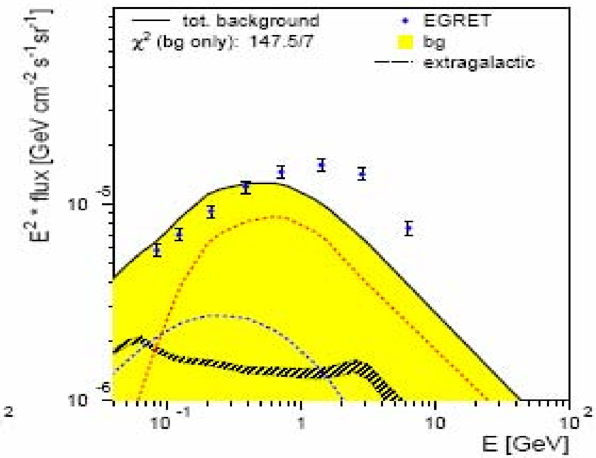
Conventional Model without DMA in 6 sky regions



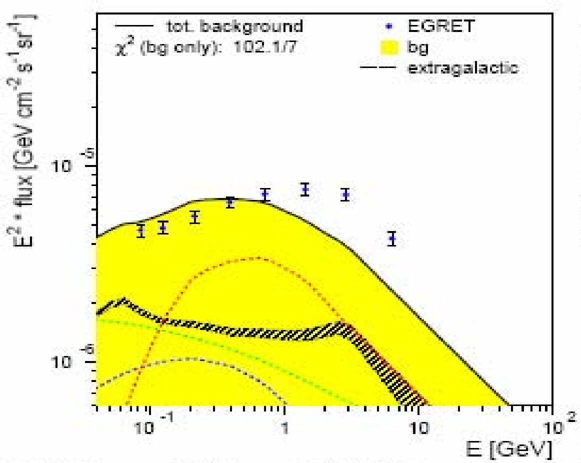
(a) Galactic center (A)



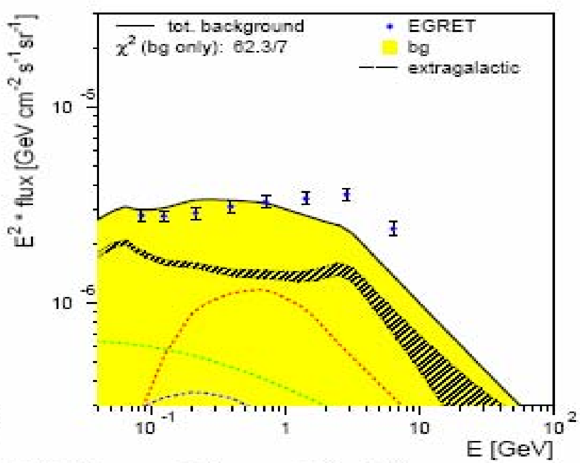
(b) Gal. plane w.o. center (B)



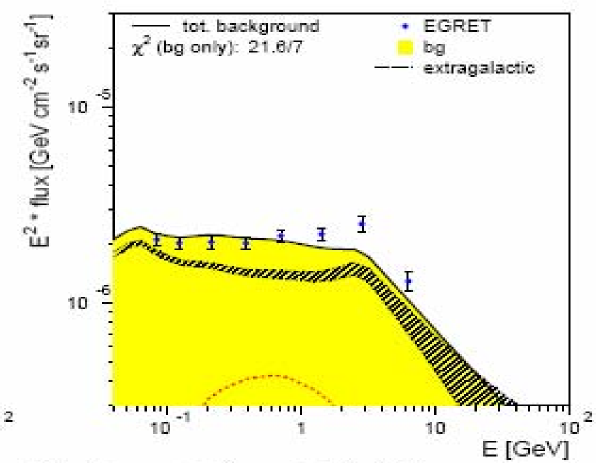
(c) Outer Galactic plane (C)



(d) Lat. 10° to 20° (D)

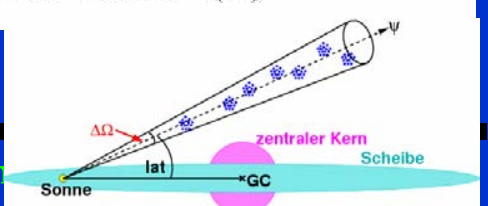


(e) Lat. 20° to 60° (E)

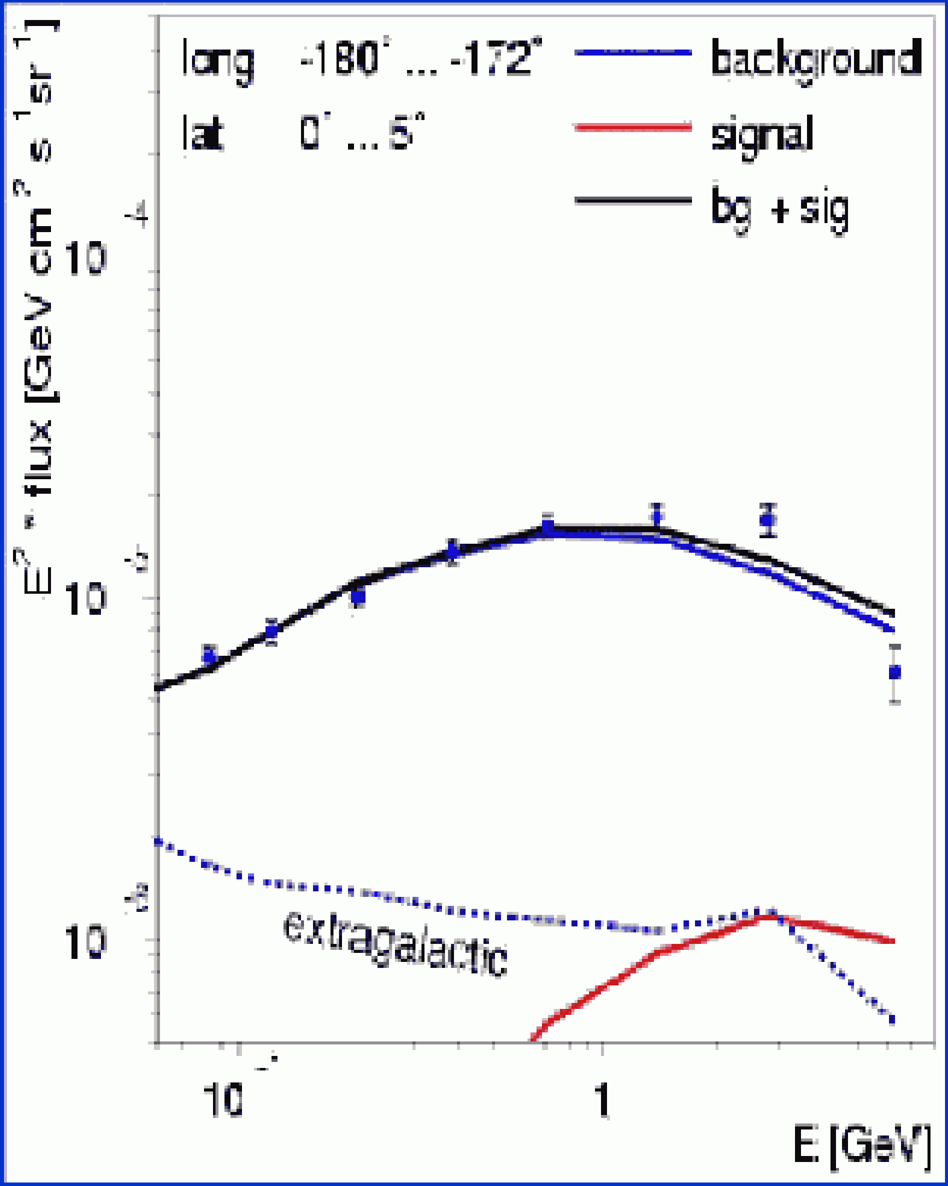


(f) Lat. 60° to 90° (F)

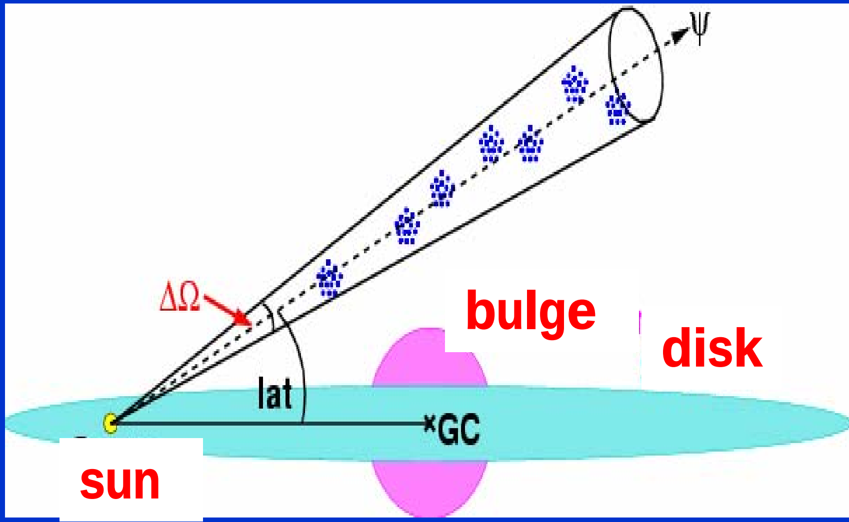
χ^2 of conventional model: 663/42 $\Rightarrow$ Prob. = 0



Fits for 180 instead of 6 regions



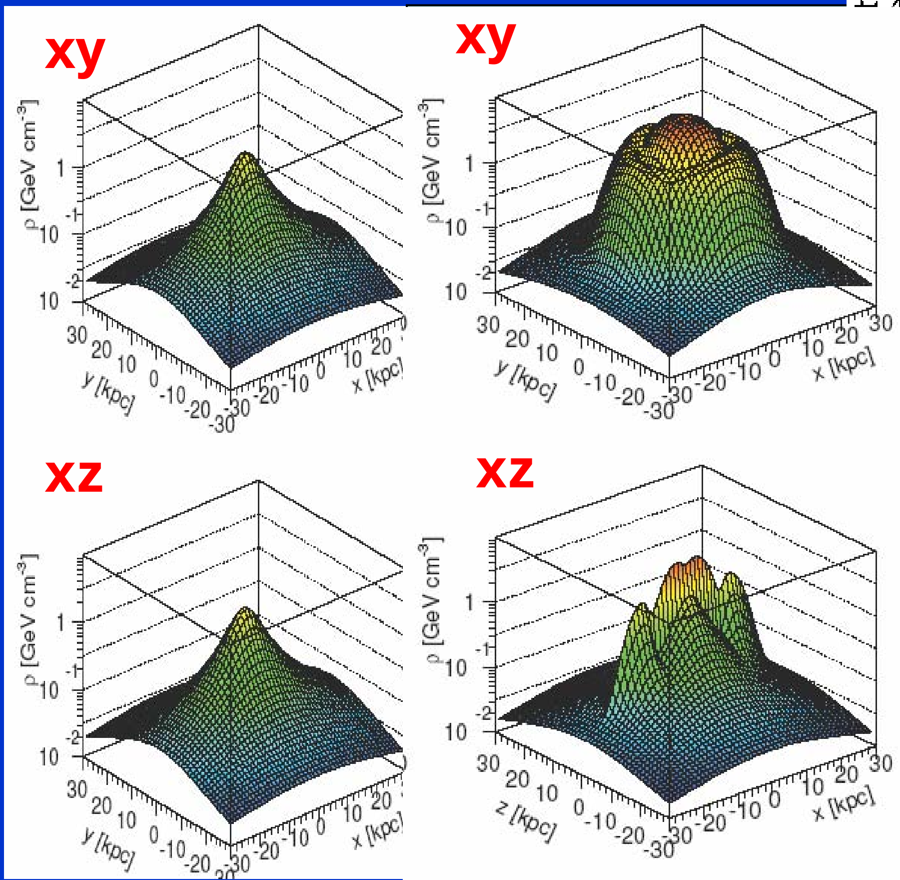
180 regions:
8^0 in long.$\Rightarrow$ 45 bins
4 bins in latitude $\Rightarrow$ $0^0<|b|<5^0$
$5^0<|b|<10^0$
$10^0<|b|<20^0$
$20^0<|b|<90^0$
$\Rightarrow$
4x45=180 bins



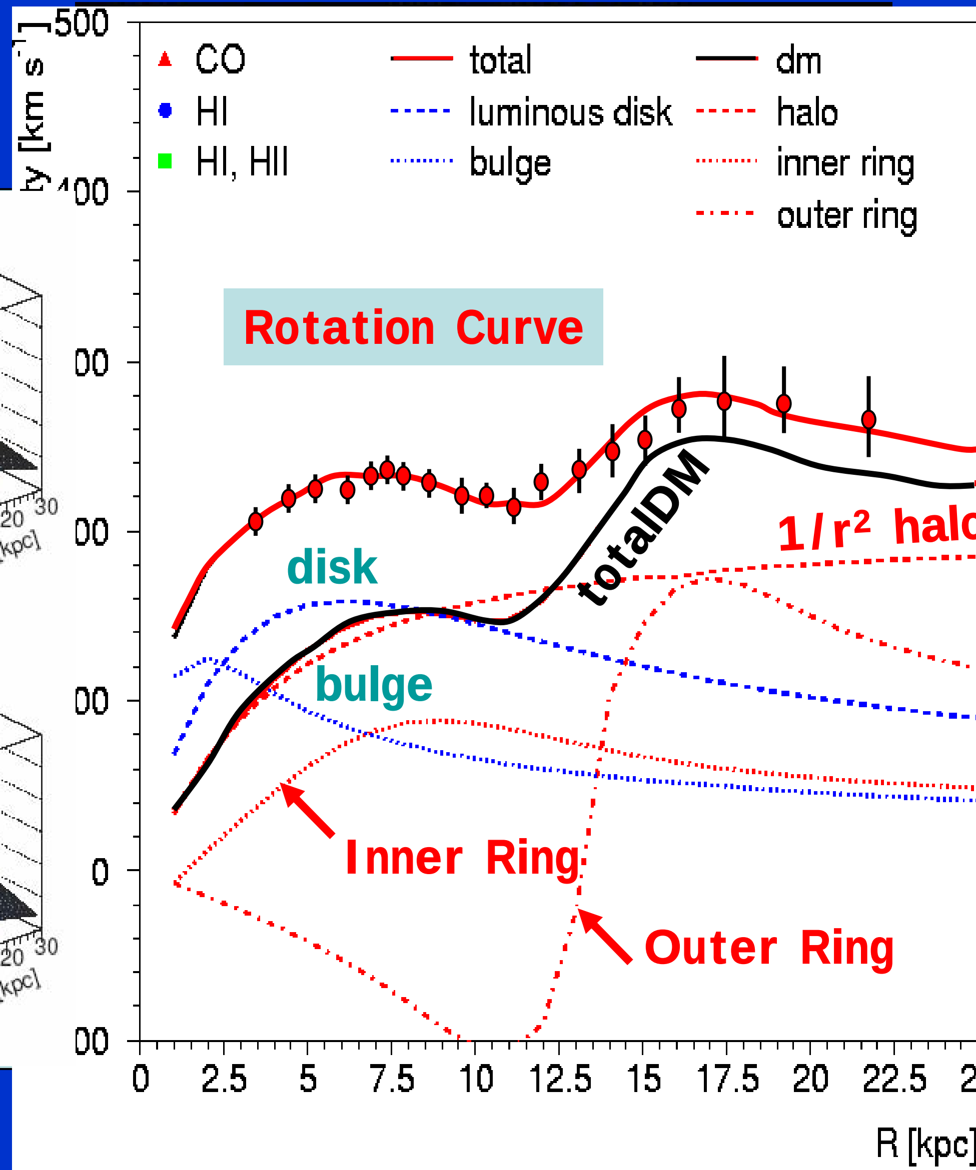
Dark Matter distribution

Expected Profile

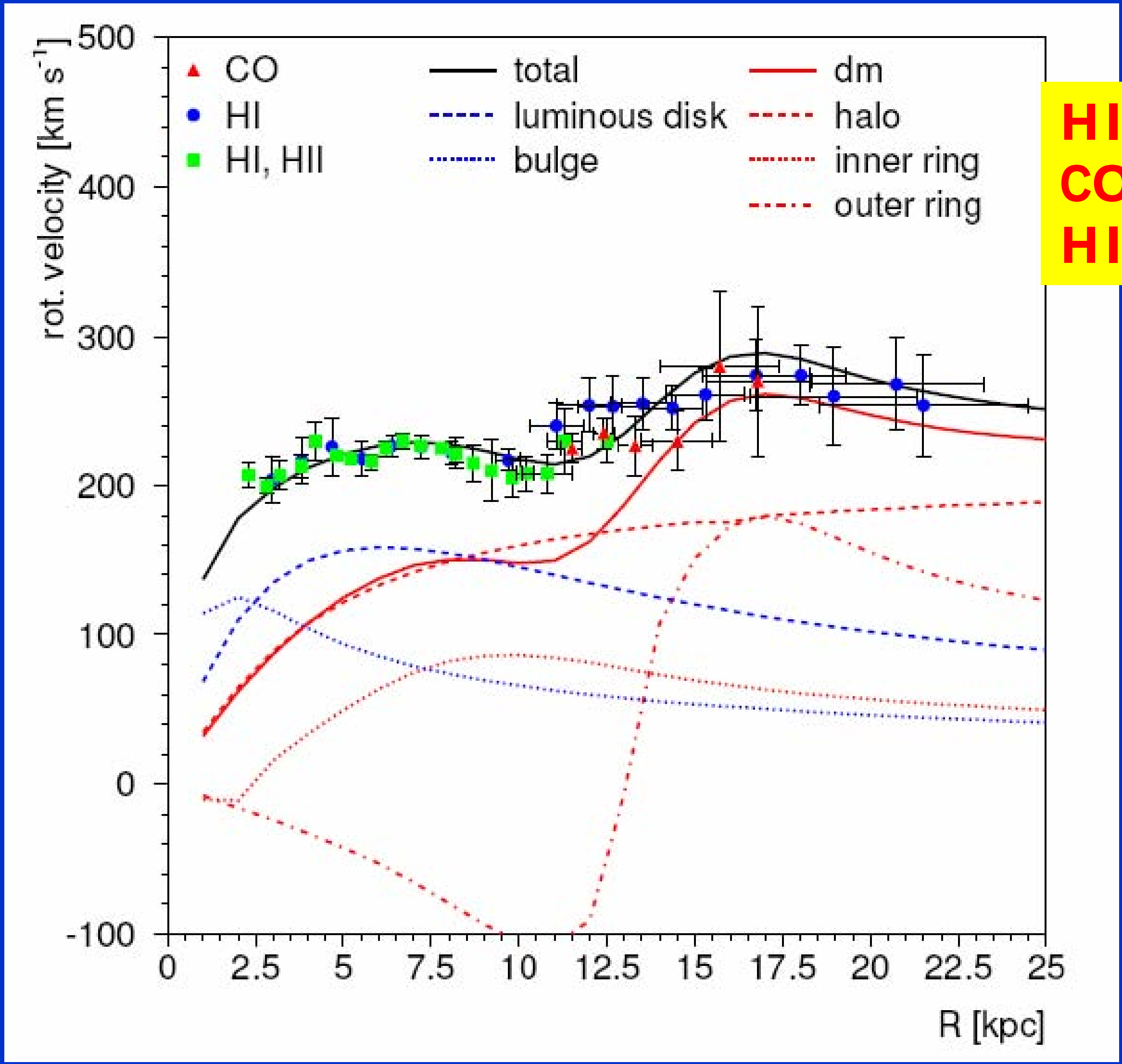
Observed Profile



Halo profile

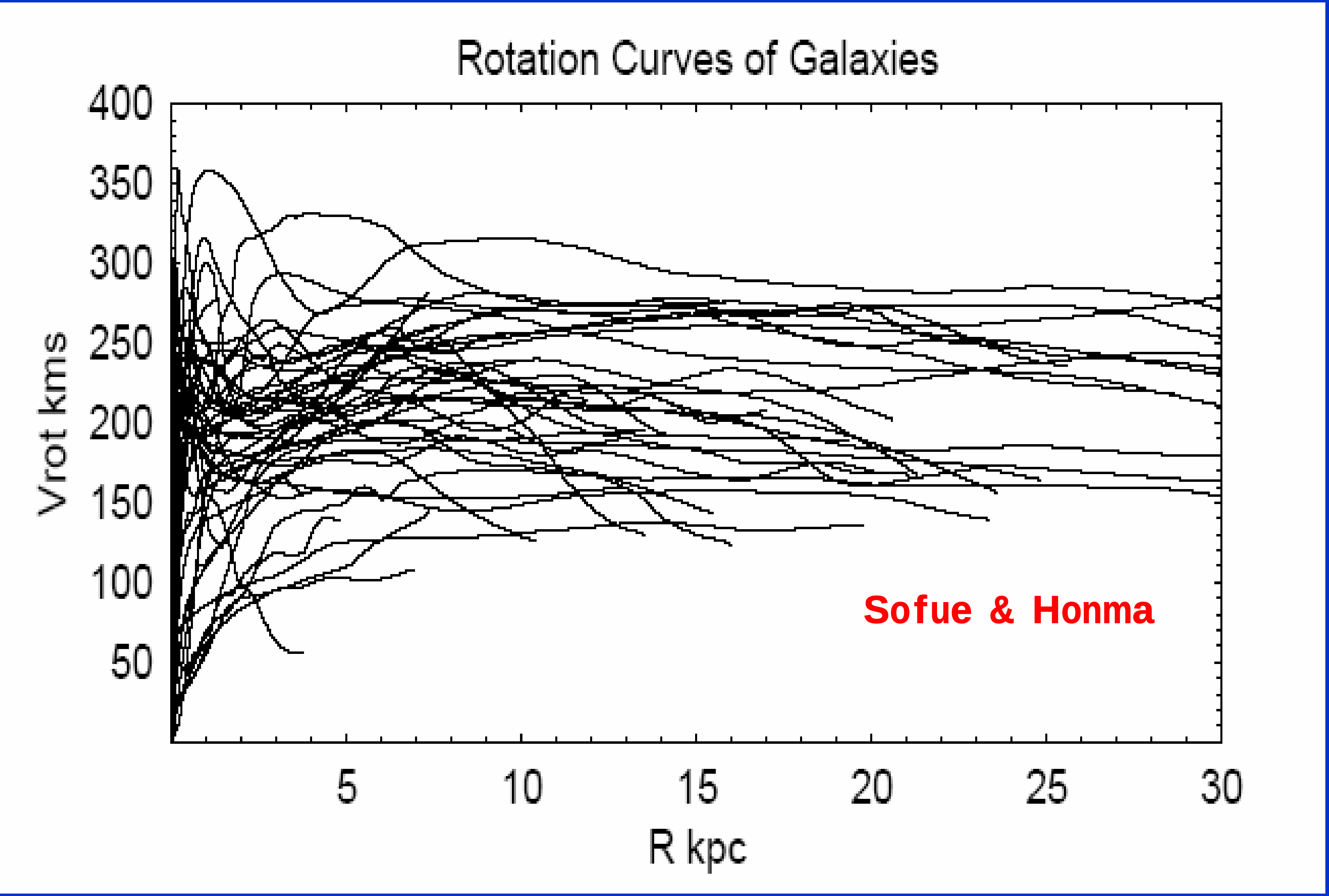


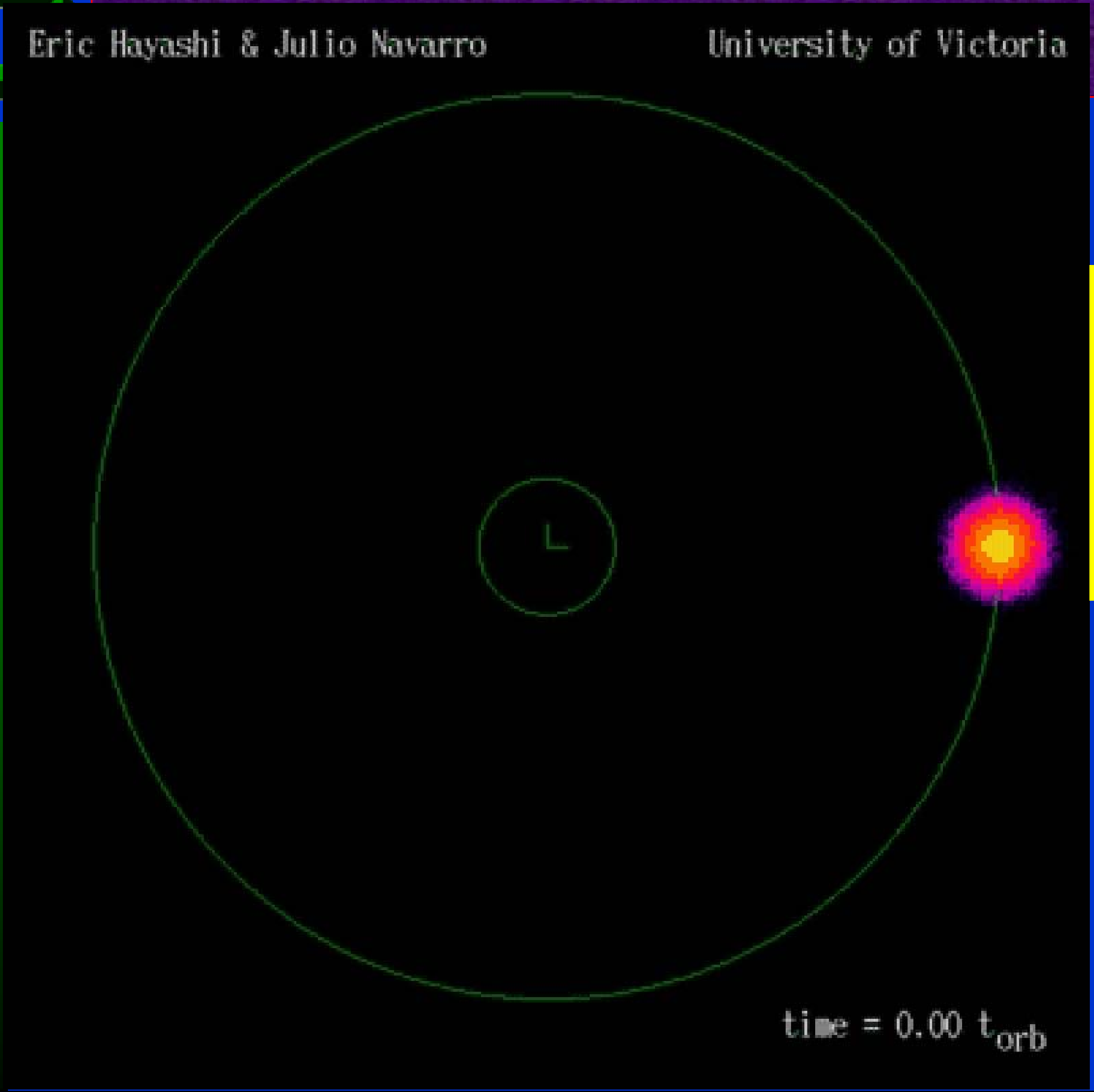
Rotation curve of Milky Way



HI=Honma & Sofue (97)
CO=Schneider &Terzian (83)
HII=Brand & Blitz(93)

Do other galaxies have bumps in rotation curves?



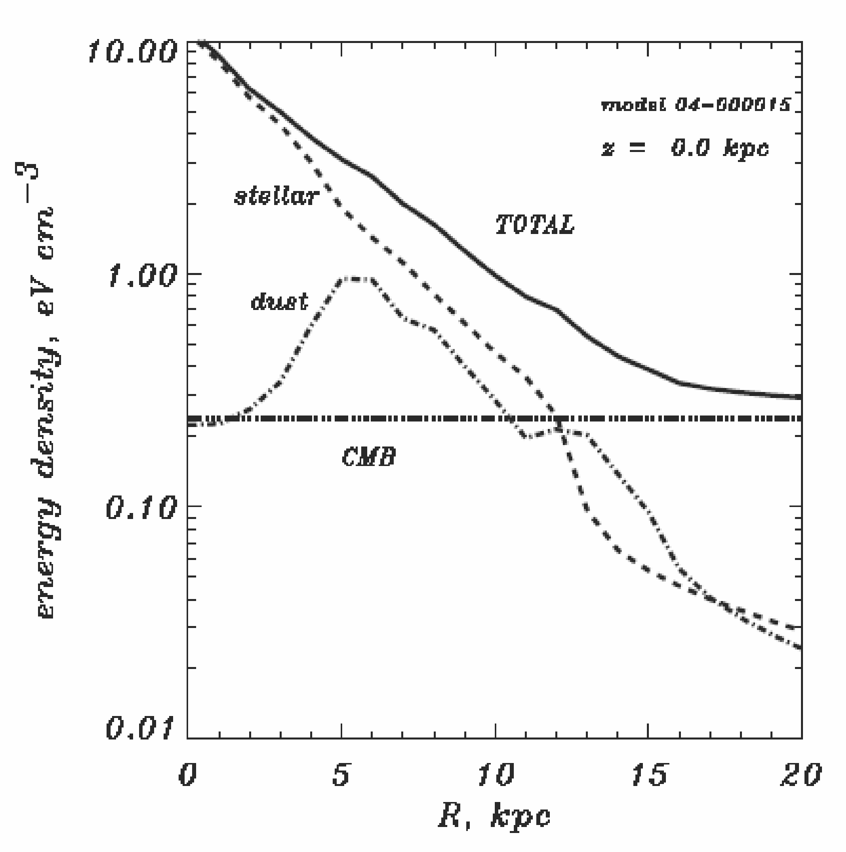


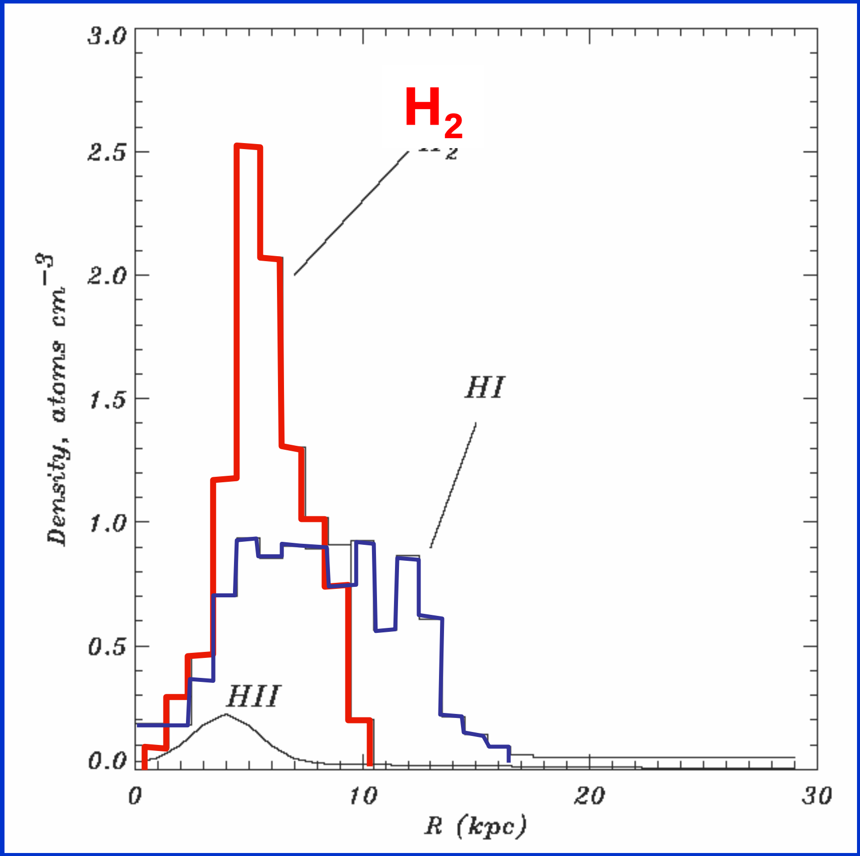
Tidal forces $\propto$ $1/r^3 \Rightarrow$ disruption mostly at pericenter

$\Rightarrow$enhancement of DM at pericenter

From Eric Hayashi

Inner Ring coincides with ring of dust and H_2 -> gravitational potential well!

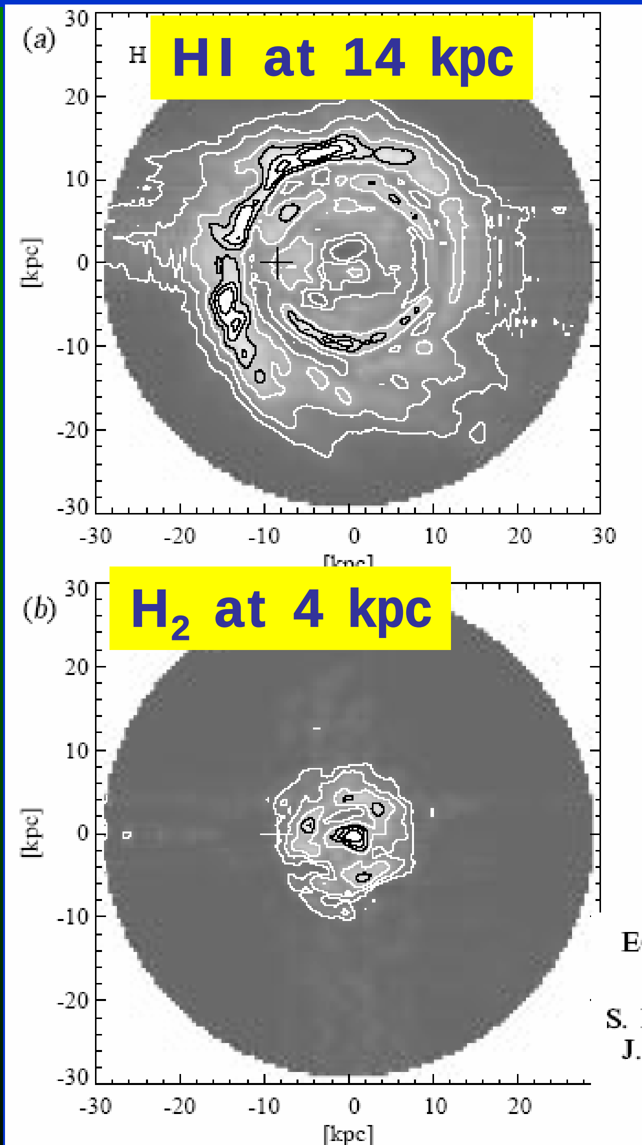


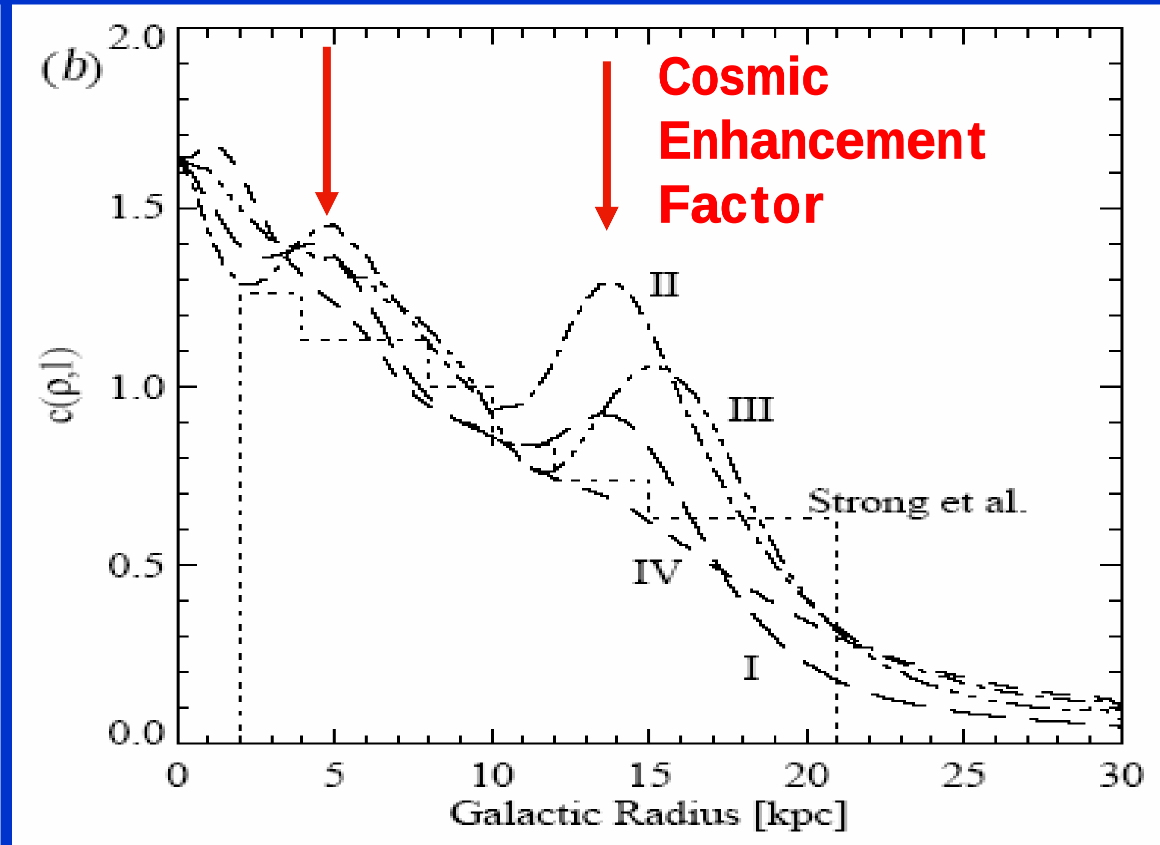


Enhancement of inner (outer) ring over $1/r^2$ profile 6 (8). Mass in rings 0.3 (3)% of total DM

4 kpc coincides with ring of neutral hydrogen molecules! Forms in presence of dust-> grav. potential well at 4-5 kpc.

Ring of enhanced gamma radiation observed by EGRET before!





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EGRET OBSERVATIONS OF THE DIFFUSE GAMMA-RAY EMISSION FROM THE GALACTIC PLANE

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Received 1995 June 13; accepted 1996 December 5

10 (wrong) objections against DMA interpretation

1) Proton spectra only measured locally. Spectra near center of galaxy, where protons are accelerated, can be different and produce harder gamma spectrum, as observed by EGRET.

Answer: proton energy loss times larger than age of universe, so proton energy spectra will become equal by diffusion This is PROVEN by the fact that we see same spectrum and same excess in inner and outer galaxy.

2) Is background known well enough to make such strong statements?

A: Background SHAPE is known, since mainly from pp collisions. Analysis does not depend on absolute fluxes from propagation models. Propagation.of gammas is straightforward.

3) Can unresolved point sources be responsible for excess?

Answer: NO, if they have similar spectra as the many resolved point sources, they would reduce the data points at low energy, thus increasing the DMA contribution if shapes are fitted. Also do not expect $1/r^2$ profile for point sources.

10 (wrong) objections against DMA interpretation

4) Does antiproton rate exclude interpretation of EGRET data? (L.B.)

Answer: Antiproton production: p+p->pbar+X: Npbar $\propto \langle\rho_p^2\rangle$
Antiproton annihilation: p+pbar-> X: $\propto \langle\rho_p^3\rangle$
$\langle\rho_p^3\rangle / \langle\rho_p\rangle^3$ can be much larger than 1 by clustering

5) Rotation curves in outer galaxy measured with different method than inner rotation curve. Can you combine? Also it depends on R_0.

Answer: first points of outer RC have same negative slope as inner RC so no problem with method. Change of slope seen for every R_0.

6) Ringlike structures have enhanced density of hydrogen, so you expect excess of gamma radiation there. Why you need DMA?

Answer: since we fit only the shapes of signal and BG, a higher gas density is automatically taken into account and DMA is needed to fit the spectral shape of the data.

7) Is EGRET data reliable enough to make such strong statements?

Answer: EGRET spectrometer was calibrated in photon beam at SLAC. Calibration carefully monitored in space. Impossible to get calibration wrong in such a way that it fakes DMA.

10 (wrong) objections against DMA interpretation

7) How can you be sure that this outer ring is from the tidal disruption of satellite galaxy, so one can expect DM there?

Answer: one observes rings for all three ingredients of a galaxy: gas, stars and DM. They cannot be part of the disk, since the thickness of the ring is a factor 20 larger than the thickness of the disk. Furthermore, very small velocity dispersion of stars

8) Is it not peculiar that the rings are in the plane of the disk?

Answer: the angular momenta of halo and disk tend to align after a certain time of precession, so rings end up in plane of the disk..

9) The inner ring was not observed as a ring of stars. How can you be sure DM concentrates there?

Answer: The density of stars and dust
in the star population. Howeve
hydrogen are proof of a gravi

10) How can one reconstruct 3D halo p
rays only along the line of sight wi

Answer: if one observes in ALL directio
see rings of Saturn (same prob

Summary

The excess of EGRET diffuse galactic gamma rays in the range between 1 and 100 GeV shows all the key features from WIMP annihilation:

1) the energy spectrum of the excess is the same in all sky directions and is consistent with the π_0 decays from monoenergetic quarks originating from WIMP annihilation for a WIMP mass between 50-100 GeV

2) the intensity distribution is used to determine the halo profile, which - outside the plane of the galaxy - is found to correspond to an isothermal (cored) profile and excludes the cuspy NFW profile

3) in the disk of the Galaxy the excess shows substructure: two toroidal rings at radii of 4 and 14 kpc (correlated with the ring of molecular hydrogen at 4 kpc and ring of stars at 14 kpc)

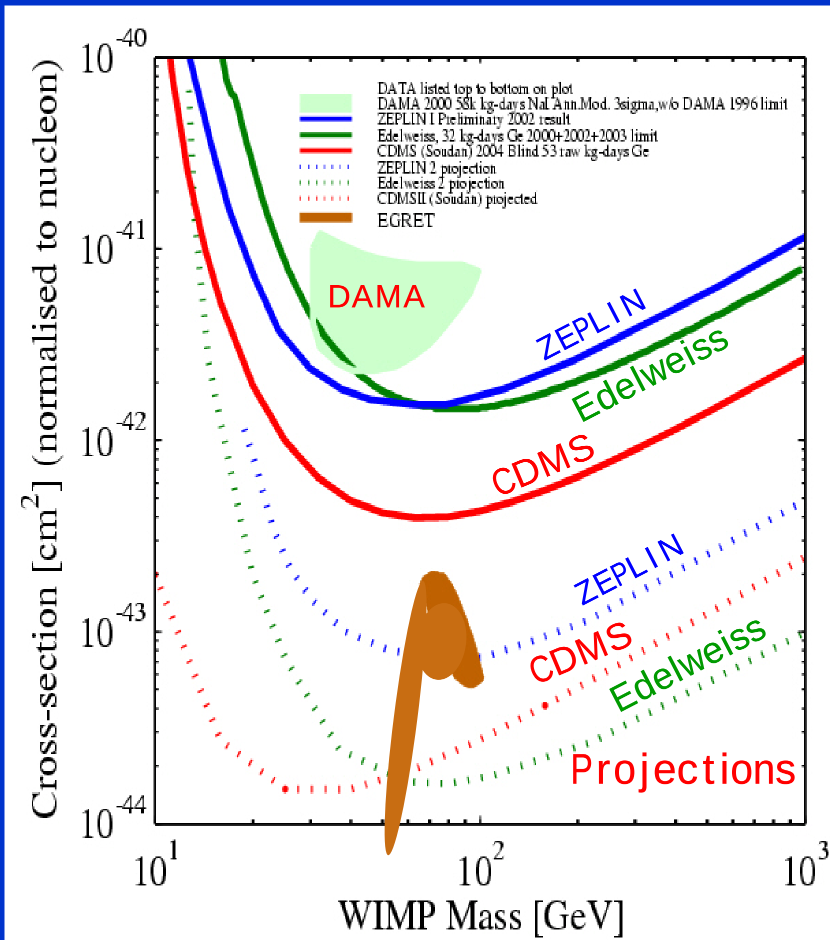
4) these rings yield a change of slope at $R=1.3R_0$ in the rotation curve and are consistent with the high local surface density

5) all features and cross sections are consistent with the WIMP being the neutralino from Minimal Supersymmetry for scalar masses ≈ 1 TeV

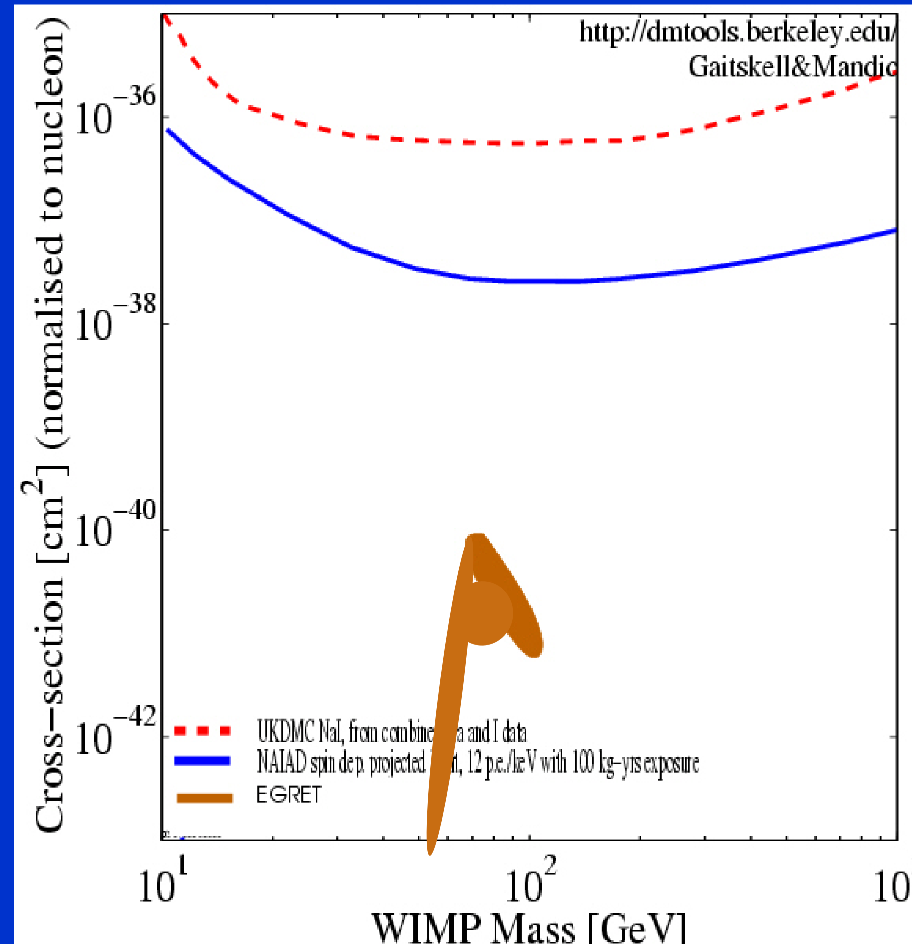
6) Alternative "conventional" models cannot explain stability of ring of stars at 14 kpc and H_2 ring of molecular gas at 4 kpc, nor change of slope in rotation curve, nor halo shape of excess

Future: Direct DM Searches

Spin-independent



Spin-dependent



Predictions from EGRET data assuming Supersymmetry

Future: Accelerators

Are results consistent with Supersymmetry?

Answer: yes, for Squarks and Sleptons in TeV range
WIMP is then bino like, i.e. in this case

DM would be the SUSY partner of the CMB

LHC/ILC Experiments will tell!