The dark connection between Canis Major, Monoceros Stream, gas flaring, the rotation curve and the EGRET excess

From EGRET excess of diffuse Galactic gamma rays
- Determination of WIMP mass
- Determination of WIMP halo (= standard halo + DM ring)

Confirmation:
- Rotation curve
- Canis Major/Monoceros stream
- Gas flaring

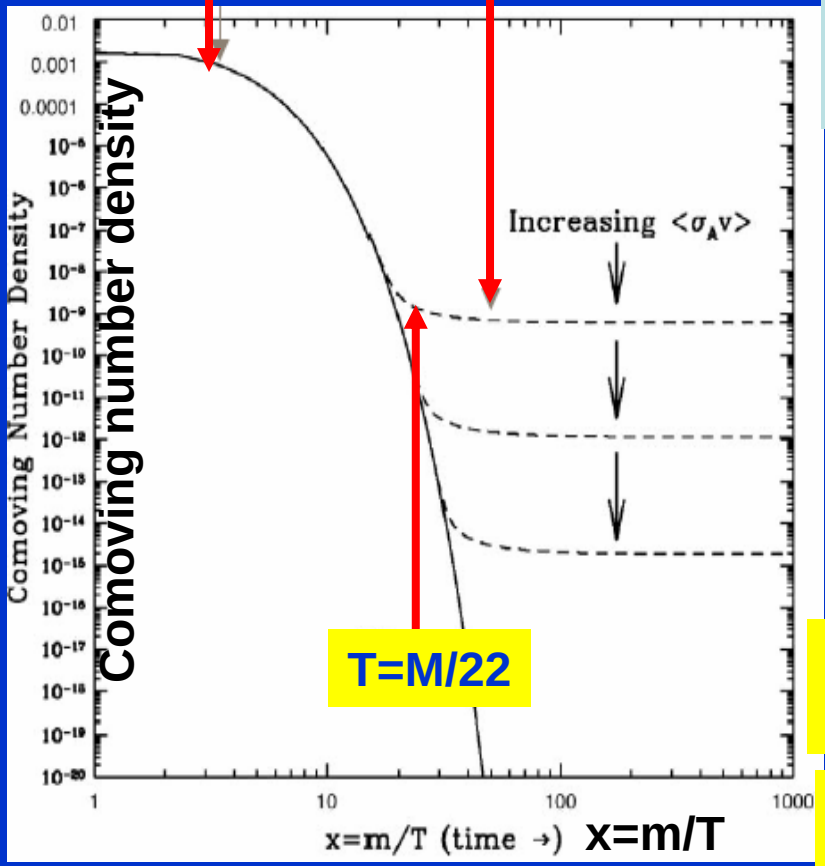
PREDICTIONS
- for LHC (if SUSY)
- for direct searches
- for solar neutrinos

Ingredients to this analysis

Expansion rate of universe determines WIMP annihilation cross section

Thermal equilibrium abundance

Actual abundance



Gary Steigmann (1979)

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

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

T=M/22: M decoupled, stable density

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

WMAP -> $\Omega h^2=0.113\pm0.009$ ->

$\langle\sigma v\rangle=2.10^{-26}$ 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!

Only assumption in this analysis:
WIMP = THERMAL RELIC!

What we get from cosmology

IF DM particles are thermal relics from early universe, they can annihilate with a cross section as large as

$\langle \sigma v \rangle = 2.10^{-26}$ cm^3/s

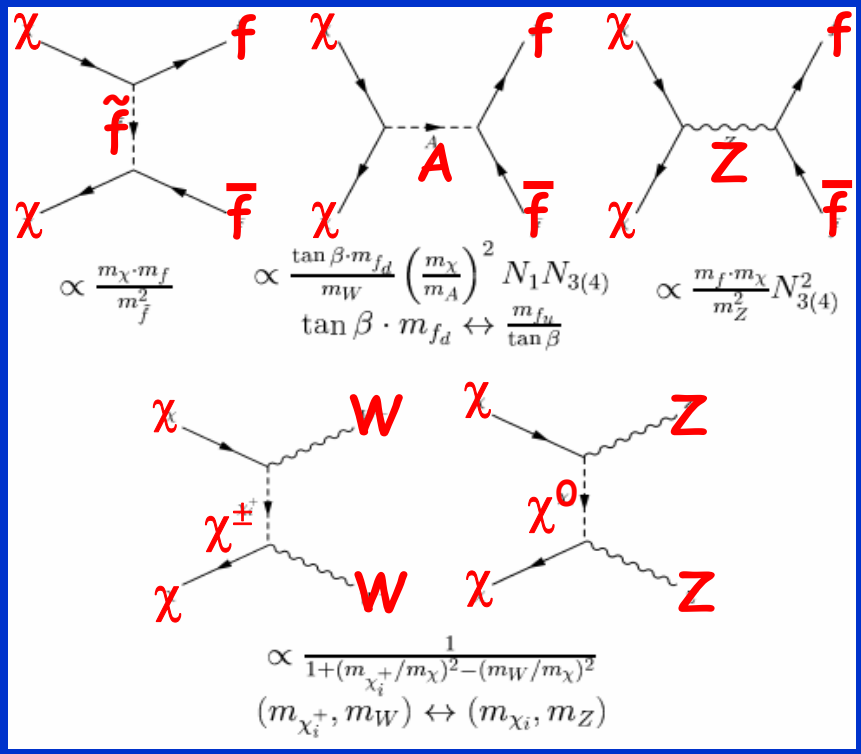
which implies an enormous rate of gamma rays from π_0 decays (produced in quark fragmentation) (Galaxy=10^{40} higher rate than any accelerator)

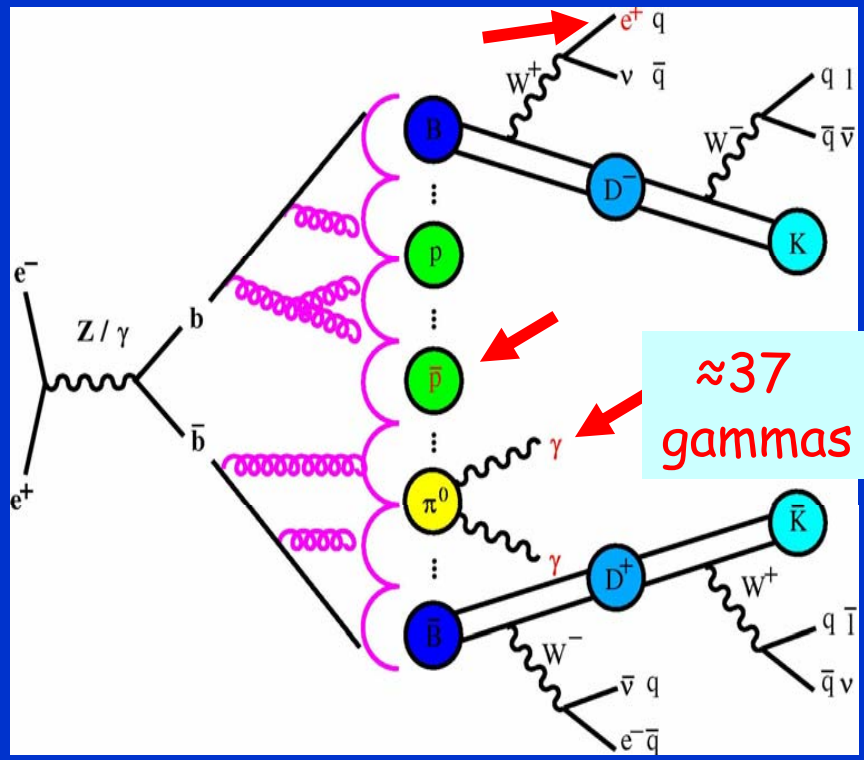
Expect large fraction of energetic Galactic gamma rays to come from DMA in this case.

Remaining ones from $p_{CR}+p_{GAS} \rightarrow \pi_0+X$, $\pi_0 \rightarrow 2\gamma$ (+some IC+brems)

This means: Galactic gamma rays have 2 components with a shape KNOWN from the 2 BEST studied reactions in accelerators: background known from fixed target exp. DMA known from e+e- annihilation (LEP)

Example of DM annihilation (SUSY)





Dominant
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair
Sum of diagrams should yield $\langle\sigma v\rangle = 2.10^{-26}$ cm^3/s to get correct relic density

Quark fragmentation known!
Hence spectra of positrons, gammas and antiprotons known!
Relative amount of γ,p,e+ known as well.

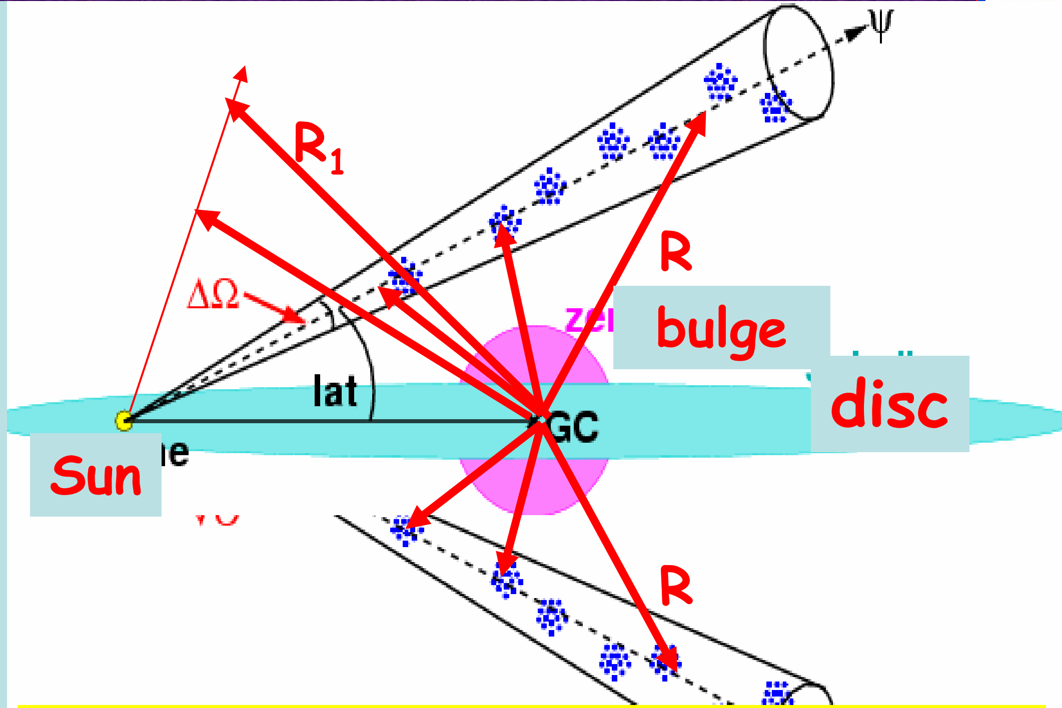
Basic principle for indirect dark matter searches

From rotation curve:

Forces: $mv^2/r=GmM/r^2$
or M/r=const.for v=cons.
and
$\rho \propto (M/r)/r^2$
$\rho \propto 1/r^2$
for flat rotation curve

Expect highest DM density
IN CENTRE OF GALAXY

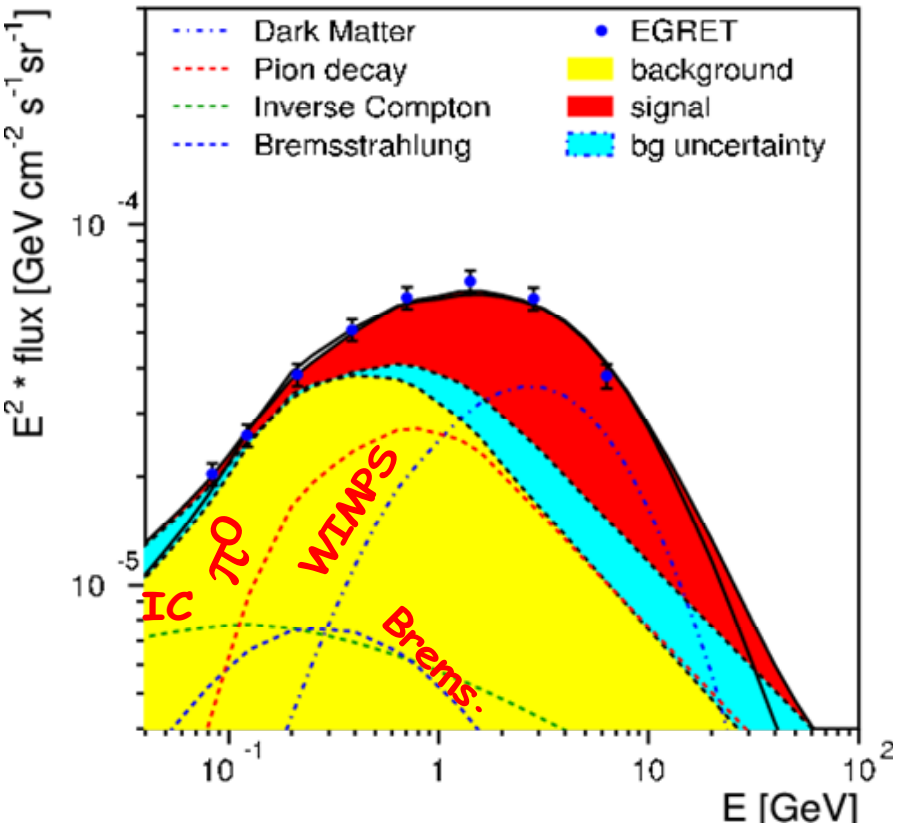
Divergent for r=0?
NFW profile$\propto$1/r
Isotherm profile const.



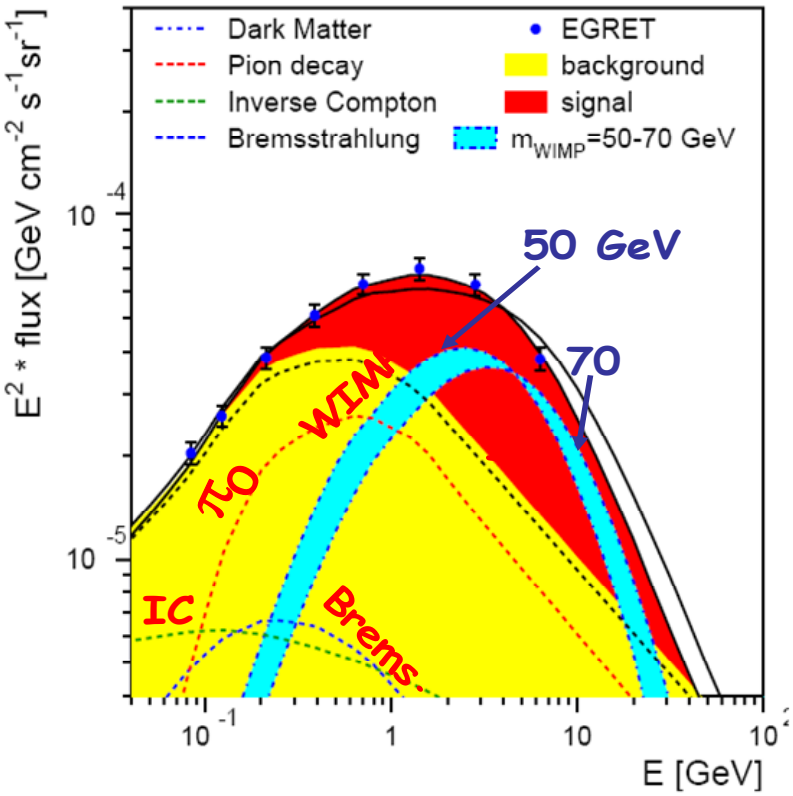
IF FLUX AND SHAPE MEASURED IN ONE DIRECTION, THEN FLUX AND SHAPE FIXED IN ALL (=180) SKY DIRECTIONS!!

THIS IS AN INCREDIBLE CONSTRAINT, LIKE SAYING I VERIFY THE EXCESS AND WIMP MASS WITH 180 INDEPENDENT MEAS.

Background + signal describe EGRET data!

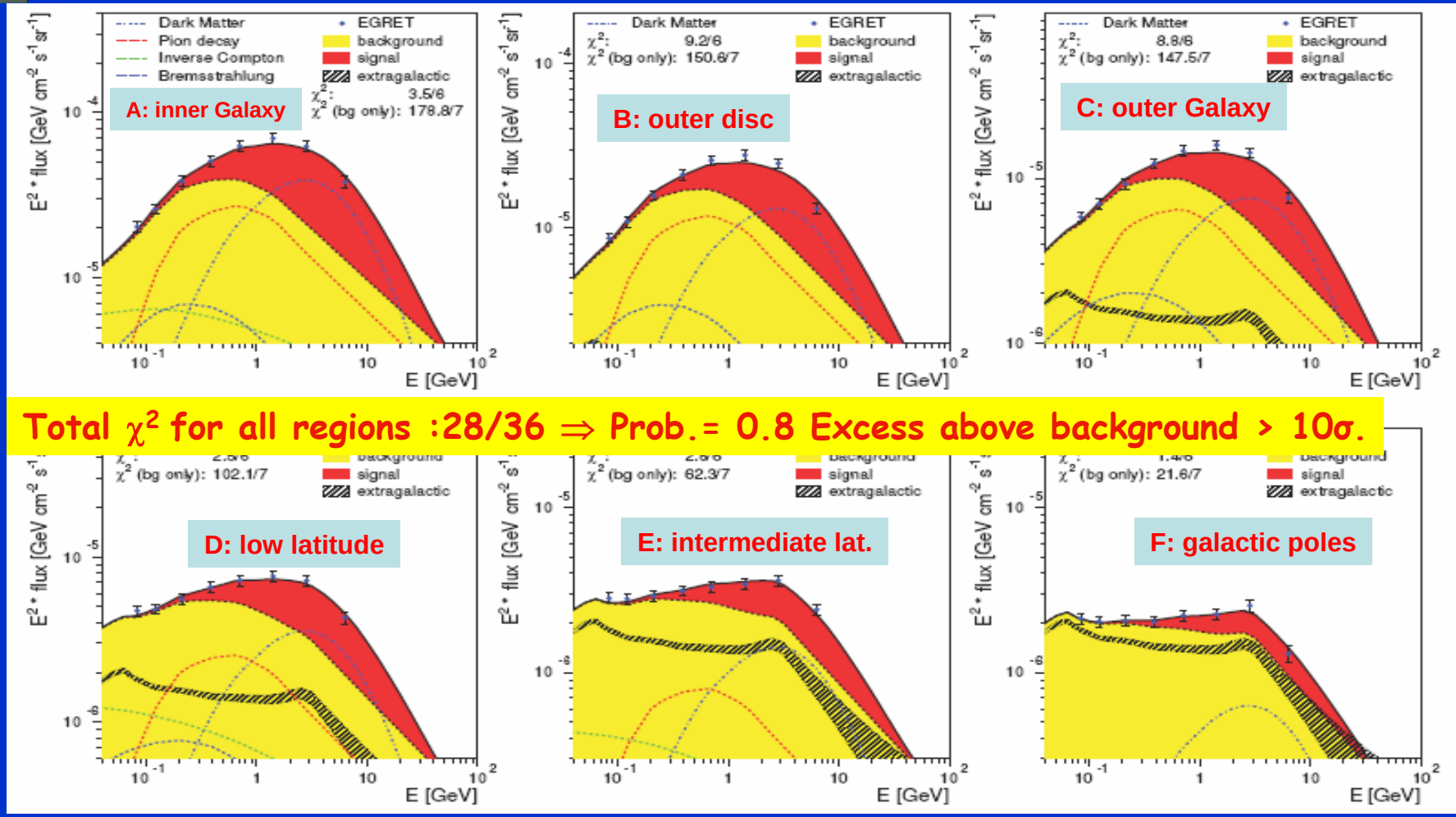


Blue: background uncertainty



Blue: WIMP mass uncertainty

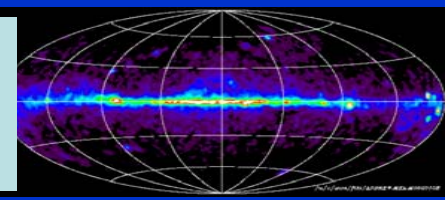
Analysis of EGRET Data in 6 sky directions



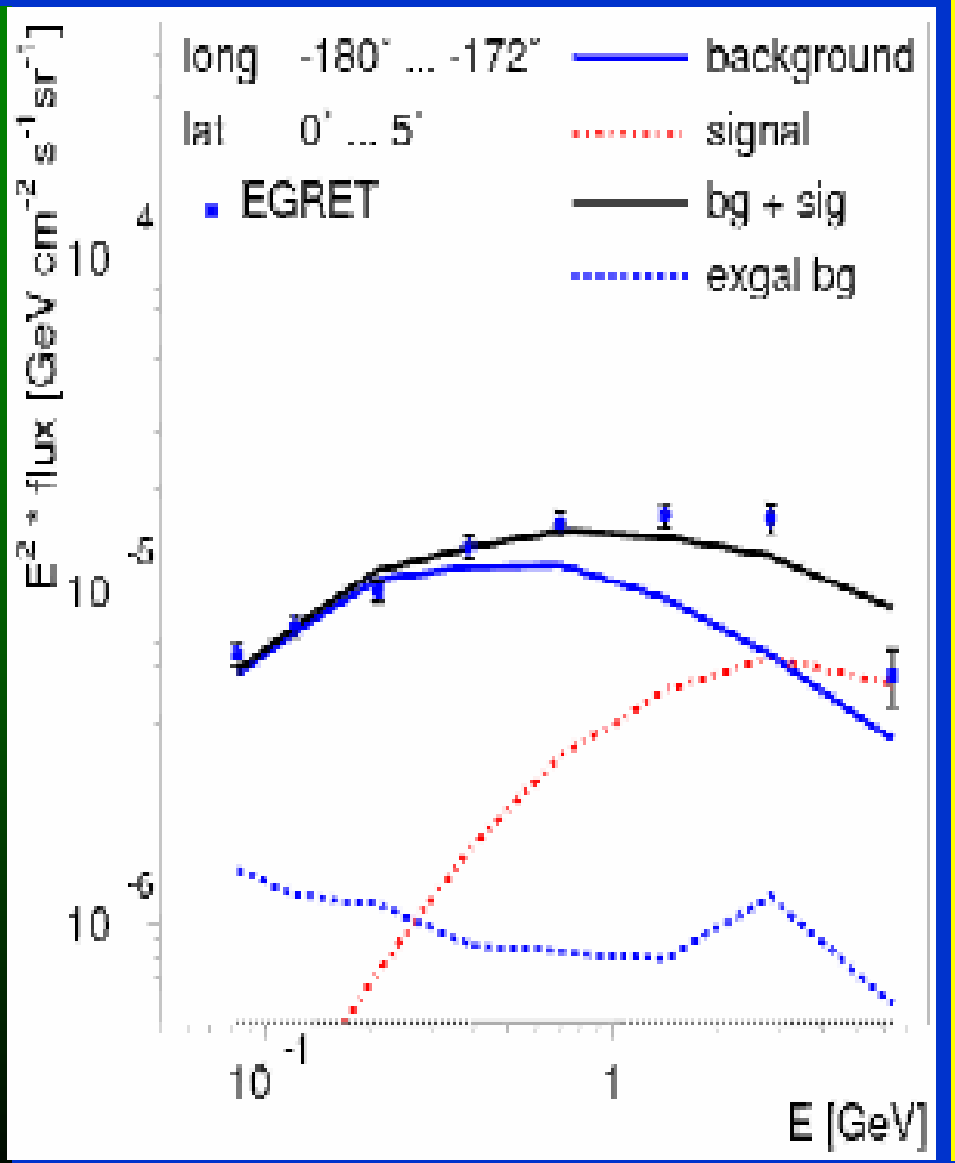
Total χ^2 for all regions :28/36 ⇒ Prob.= 0.8 Excess above background > 10σ.

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 ($60-90^0$)



Fits for 180 instead of 6 regions



180 regions:
8^0 in longitude ⇒ 45 bins
4 bins in latitude ⇒ $0^0<|b|<5^0$
$5^0<|b|<10^0$
$10^0<|b|<20^0$
$20^0<|b|<90^0$ ⇒

4x45=180 bins ⇒
>1400 data points.
Reduced $\chi^2\approx1$ with 7% errors
BUT NEEDED IN ADDITION to $1/r^2$ profile, substructure in the form of 2 doughnut-like rings in the Galactic disc!

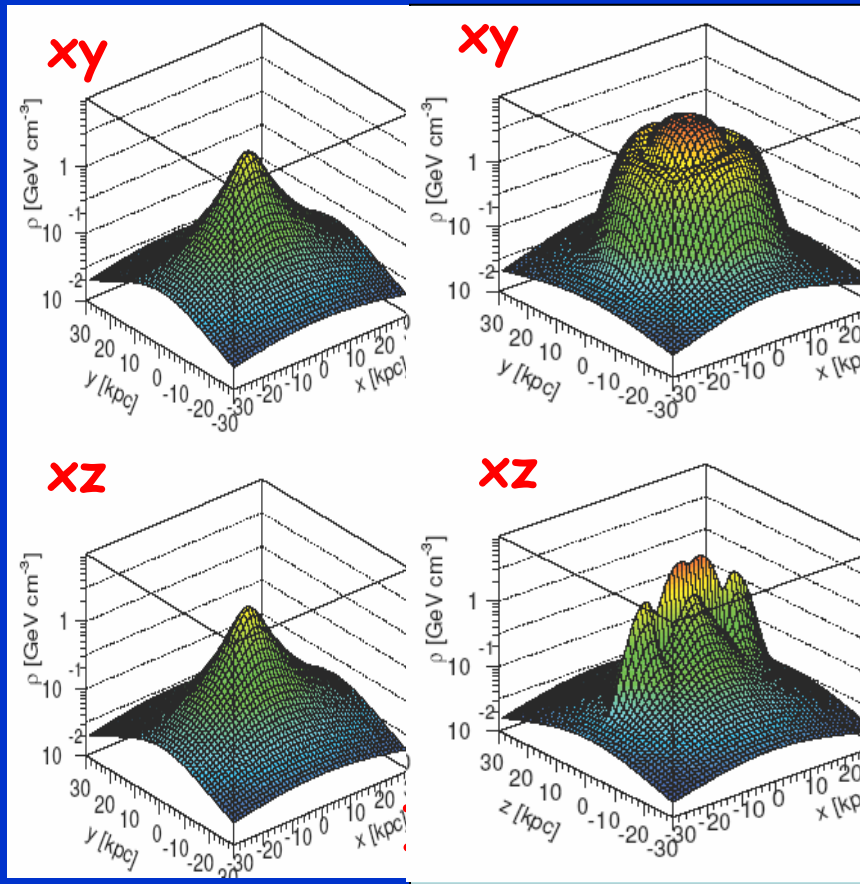
ONE RING COINCIDES WITH ORBIT FROM CANIS MAJOR DWARF GALAXY which loses mass along orbit by tidal forces

OTHER RING coincides with H_2 ring

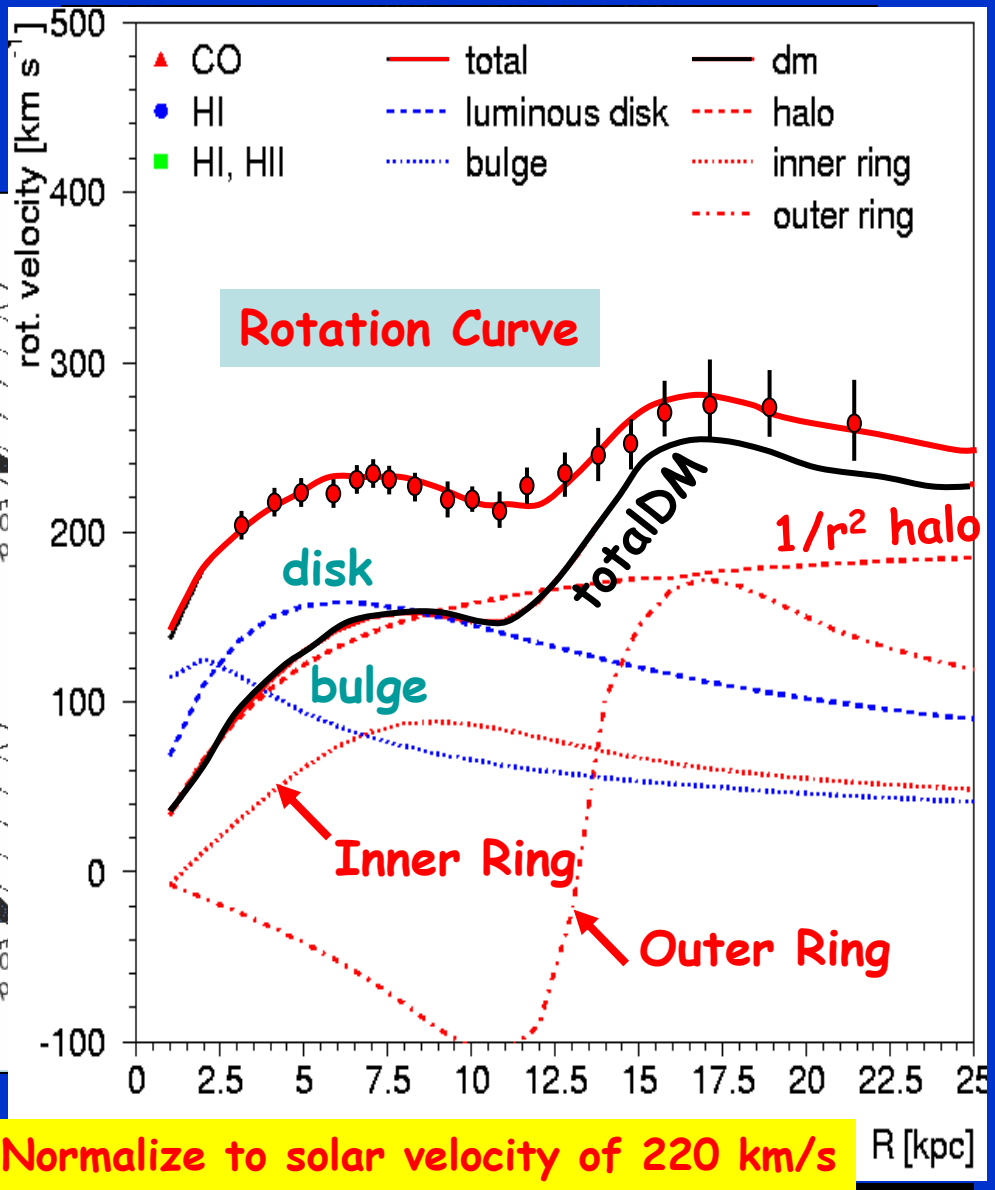
Dark Matter distribution

Expected Profile

Observed Profile

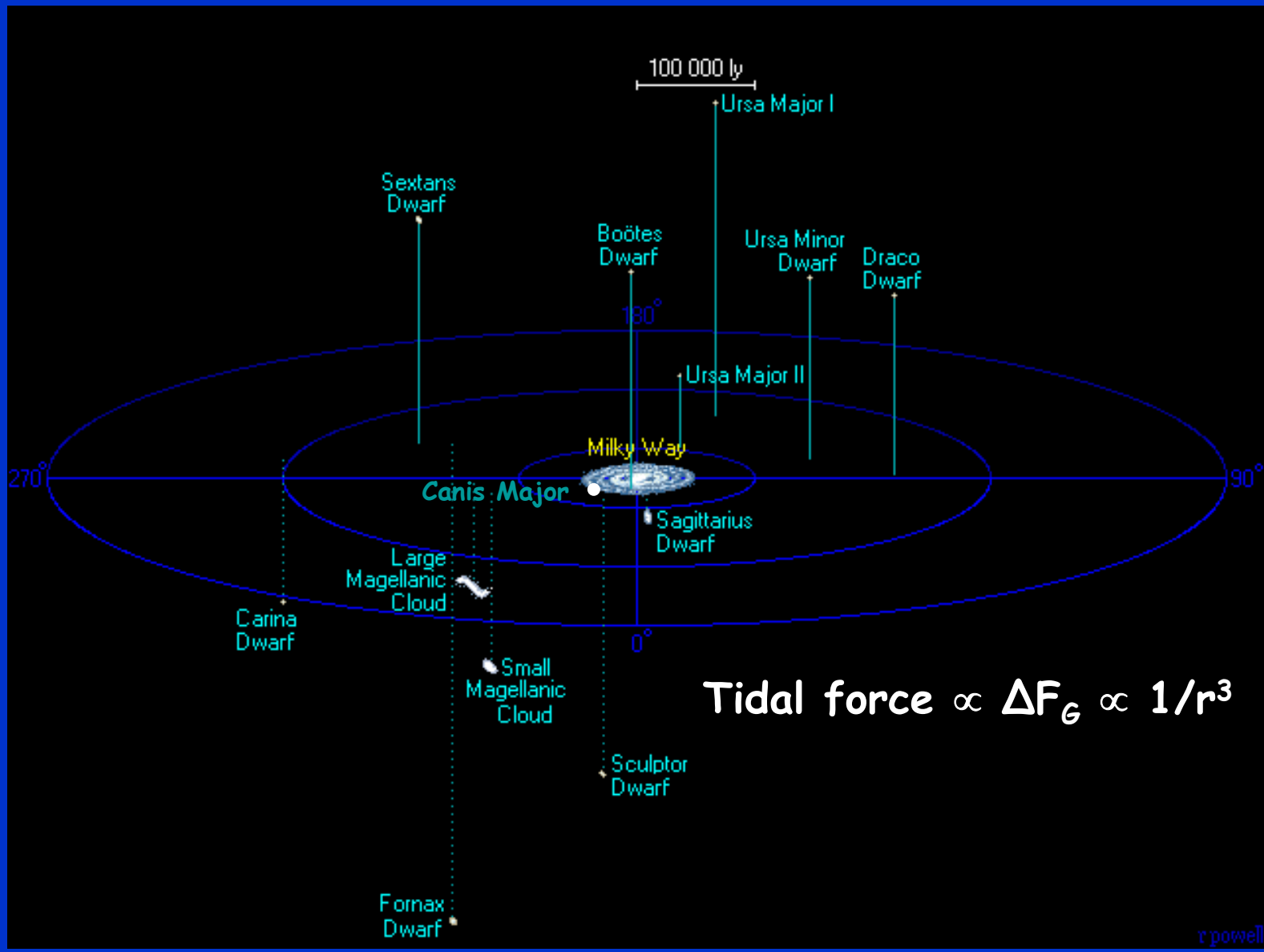


Halo profile



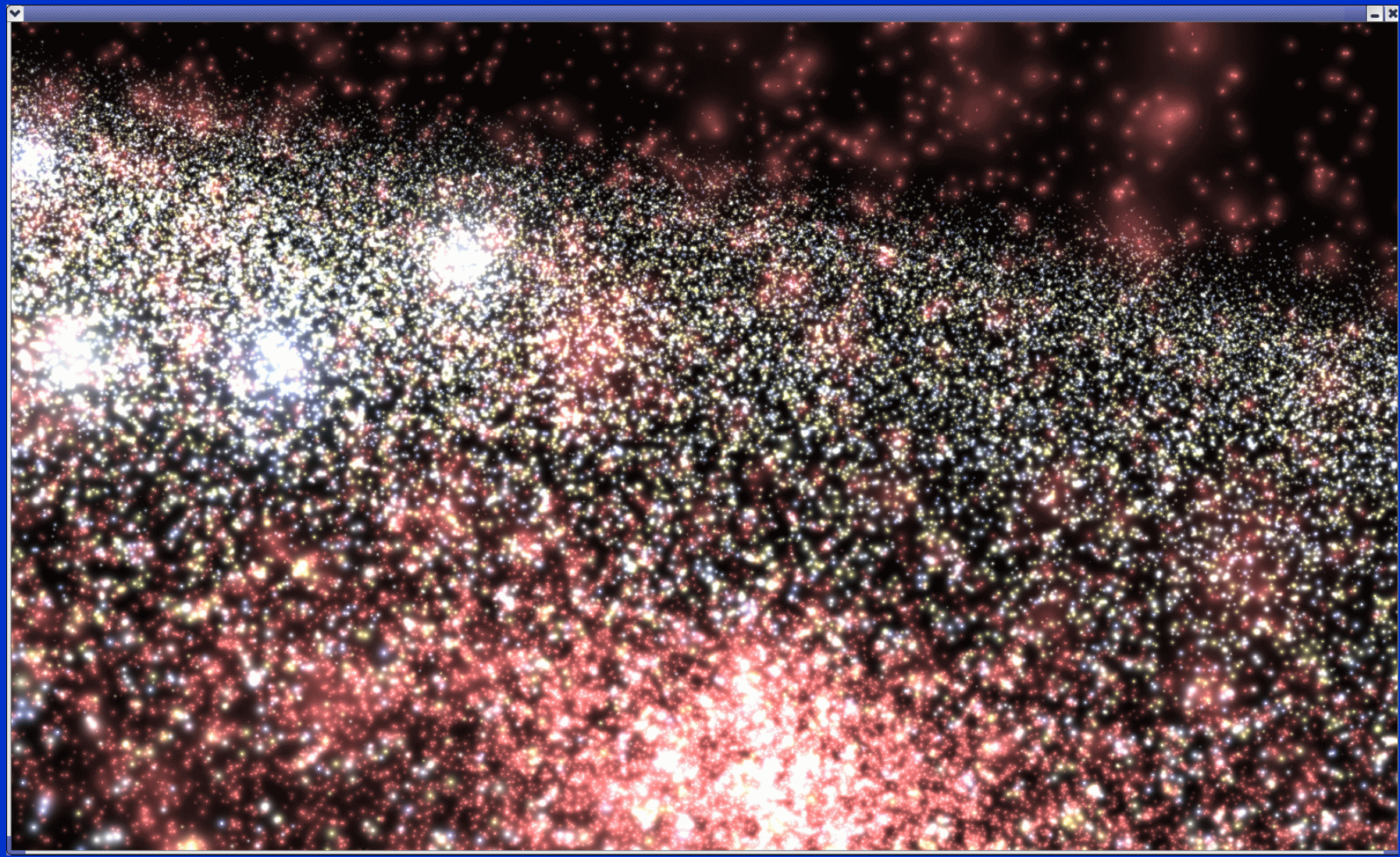
Normalize to solar velocity of 220 km/s

The Milky Way and its 13 satellite galaxies

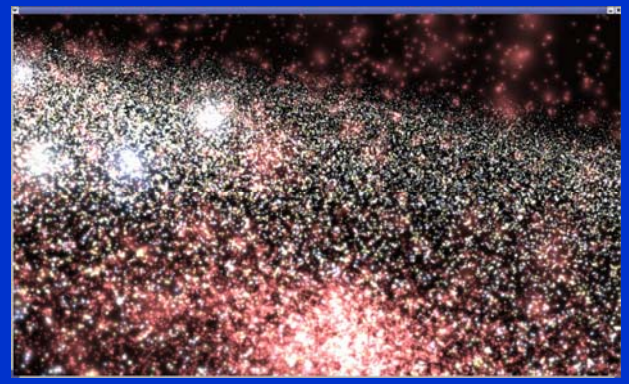


Tidal force $\propto \Delta F_G \propto 1/r^3$

Artistic view of Canis Major Dwarf just below Galactic disc



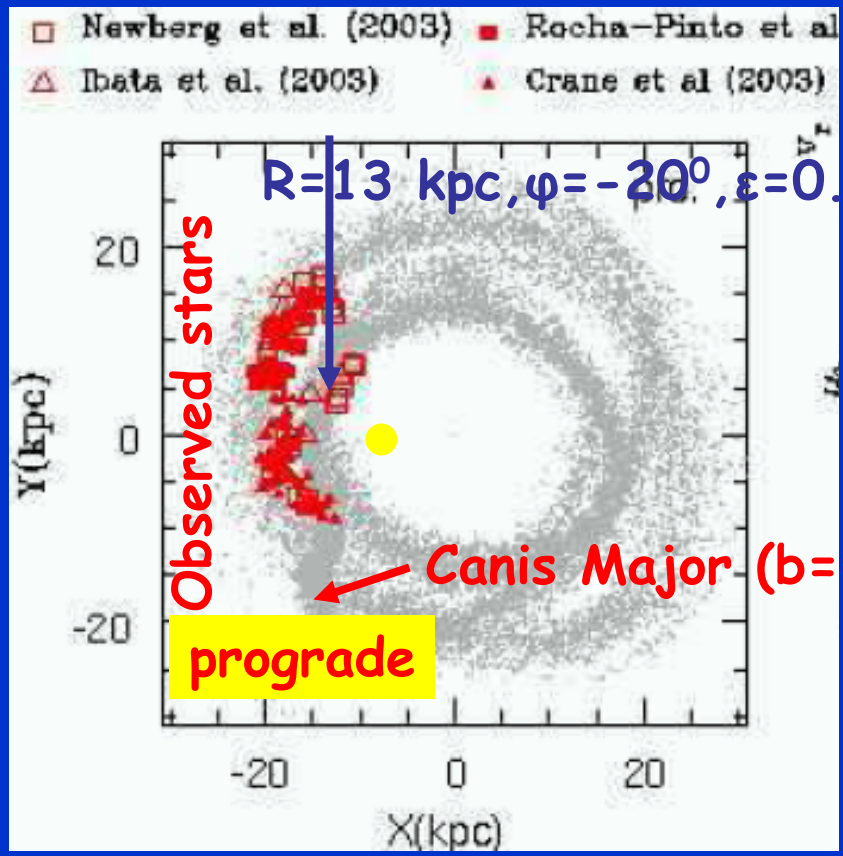
Canis Major Dwarf orbits from N-body simulations to fit visible ring of stars at 13 and 18 kpc

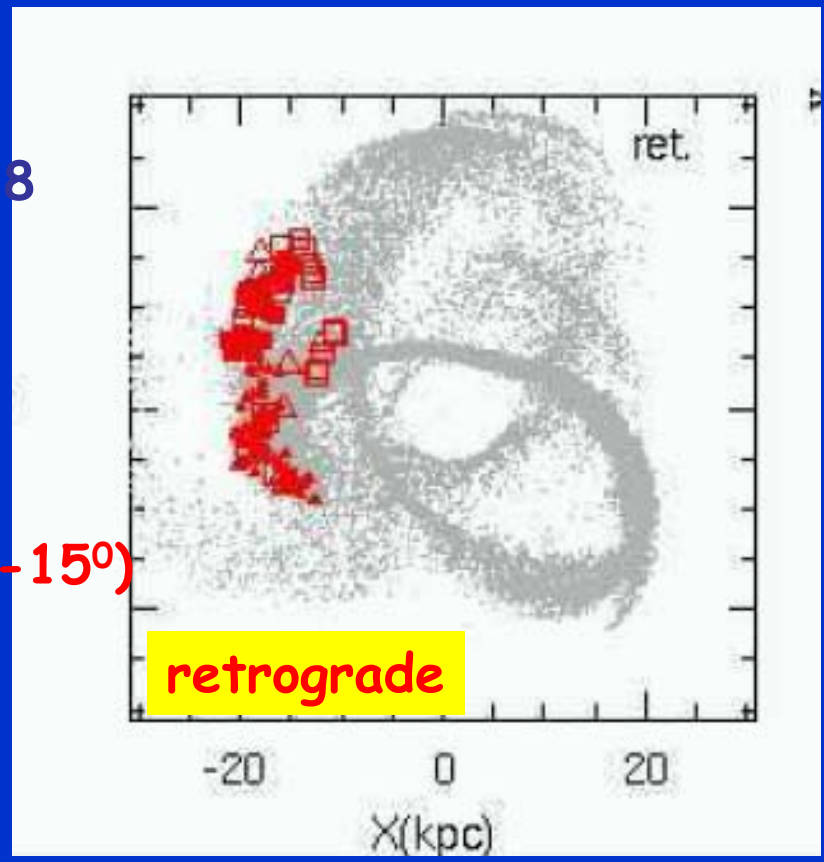


Movie from Nicolas Martin, Rodrigo Ibata
http://astro.u-strasbg.fr/images_ri/canm-e.html

Canis Major leaves at 13 kpc tidal stream of gas(10^6 $M_\odot$ from 21 cm line), stars (10^8 $M_\odot$,visible), dark matter (10^{10} $M_\odot$, EGRET)

N-body simulation from Canis-Major dwarf galaxy

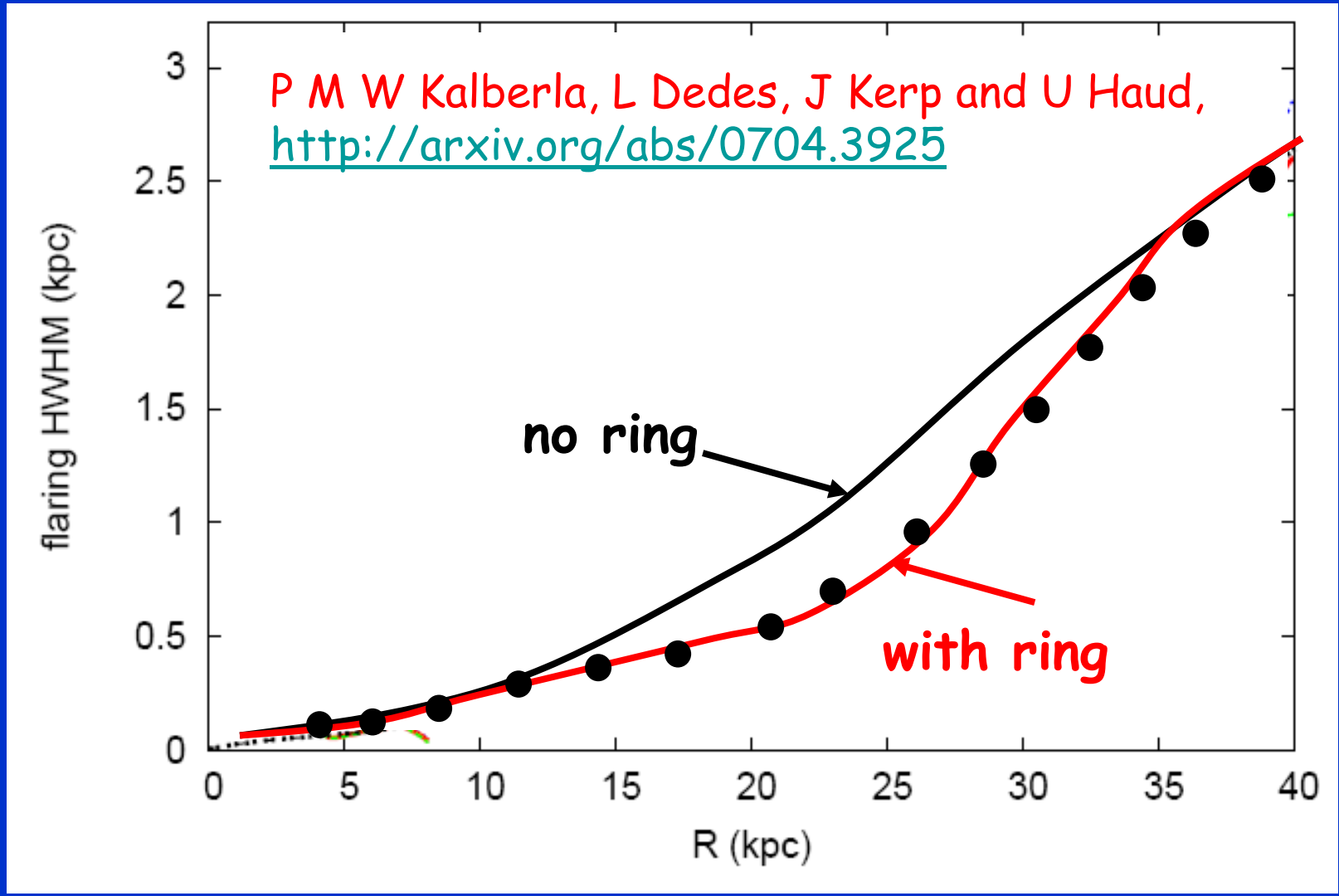




A comprehensive model for the Monoceros tidal stream

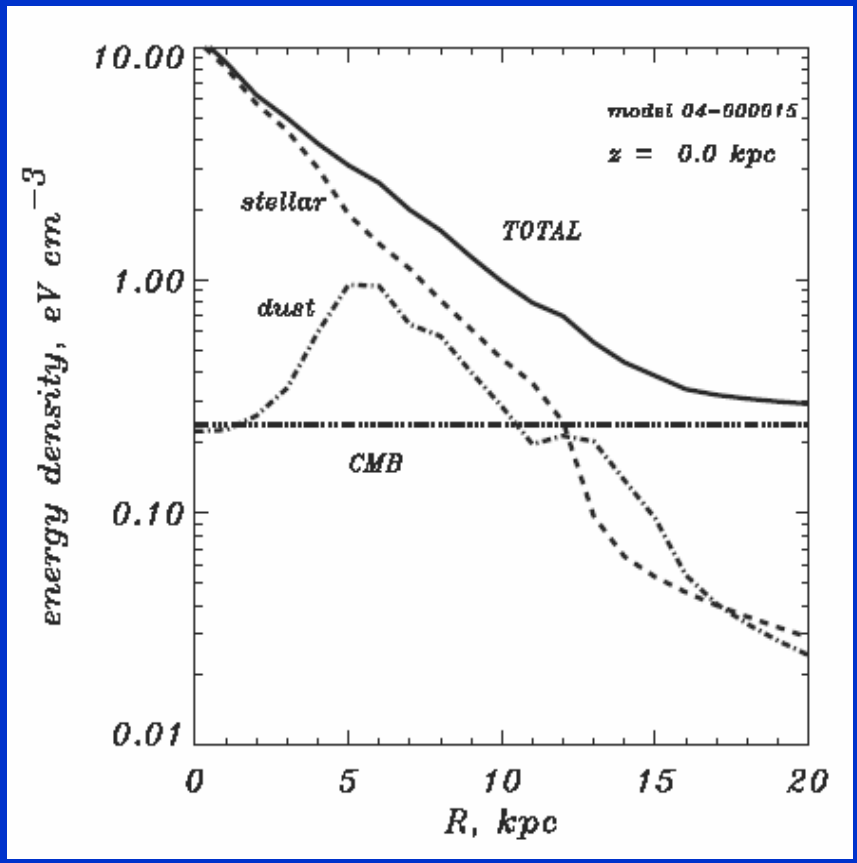
J. Peñarrubia[1], D. Martínez-Delgado[1], H.W. Rix[1], M.A Gómez-Flechoso[2], J. Munn[3], H. Newberg[4], E.F. Bell[1], B. Yanny[5], D. Zucker[1], E. K. Grebel[6]

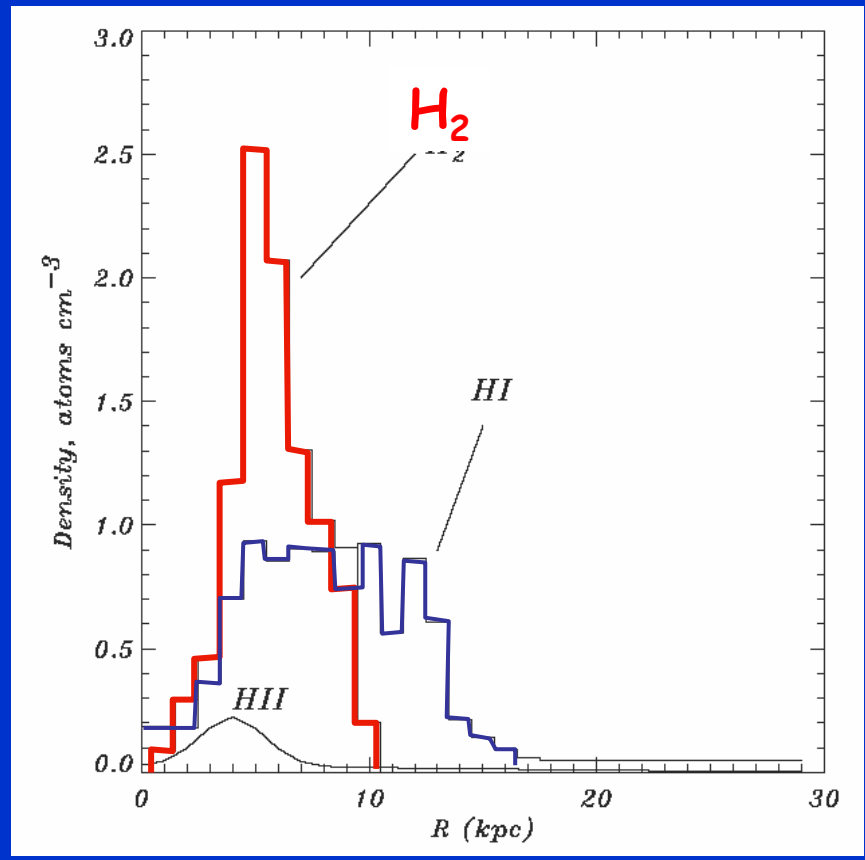
Gas flaring in the Milky Way



Gas flaring needs EGRET ring with mass of $2.10^{10} M_{\odot}$!

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!
$H+H \rightarrow H_2$ in presence of dust-> grav. potential well at 4-5 kpc.

8 physics questions answered SIMULTANEOUSLY if WIMP = thermal relic

- **Astrophysicists:**
  What is the origin of "GeV excess" of diffuse Galactic Gamma Rays? A: DM annihilation
- **Astronomers:**
  Why a change of slope in the galactic rotation curve at $R_0 \approx 11$ kpc? A: DM substructure
  Why ring of stars at 13 kpc?
  Why ring of molecular hydrogen at 4 kpc?
  Why S-shape in gas flaring?
- **Cosmologists:** How is DM annihilating? A: into quark pairs
  How is Cold Dark Matter distributed? A: standard profile + substructure
- **Particle physicists:**
  Is DM annihilating as expected in Supersymmetry?

  A: Cross sections perfectly consistent with mSUGRA for light gauginos, heavy squarks/sleptons

What about Supersymmetry?

Perfectly consistent with mSUGRA, see Talk by Christian Sander

What if DM is clumpy?

See talk by Martin Niegel?

Do antiproton data exclude interpretation of EGRET data?

Bergstrom et al. astro-ph/0603632, Abstract:

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

Answer: option that DarkSusy is wrong much more likely
See talk by I. Gebauer

Summary

>>10σ EGRET excess shows intriguing hint that:

WIMP is thermal relic with expected annihilation into quark pairs

DM becomes visible by gamma rays from fragmentation
(30-40 gamma rays of few GeV pro annihilation from π_0 decays)

Results rather model independent, since only KNOWN spectral shapes of signal and background used, NO model dependent calculations of abs.fluxes. Different shapes or unknown experimental problems may change the gamma ray flux and/or WIMP mass, BUT NOT the distribution in the sky.

SPATIAL DISTRIBUTION of annihilation signal is signature for DMA which clearly shows that EGRET excess is tracer of DM by fact that one can construct rotation curve and tidal streams from gamma rays.

DM interpretation strongly supported independently by gas flaring