The FERMI Diffuse Gamma-Ray Sky in Comparison with Galactic Models with and without Dark Matter

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Outline

- Present status
- Template fit ⇒ normalization for different components
- Missing hard component towards GC: Fermi Bubble or DM?
- Nature of Fermi Bubble: more likely outflow by CR pressure in cylinder between 2 and 6 kpc than Bubble from GC?
- Closer look at inner 1^{o} of GC: accretion disk yielding hard spectrum by flattened CR spectrum?
- Excellent template fit in all sky directions ⇒ stringent limits on DMA: limit on 700 GeV WIMP below <σv> from relic density

Word of Caution

Beware: everything preliminary!!

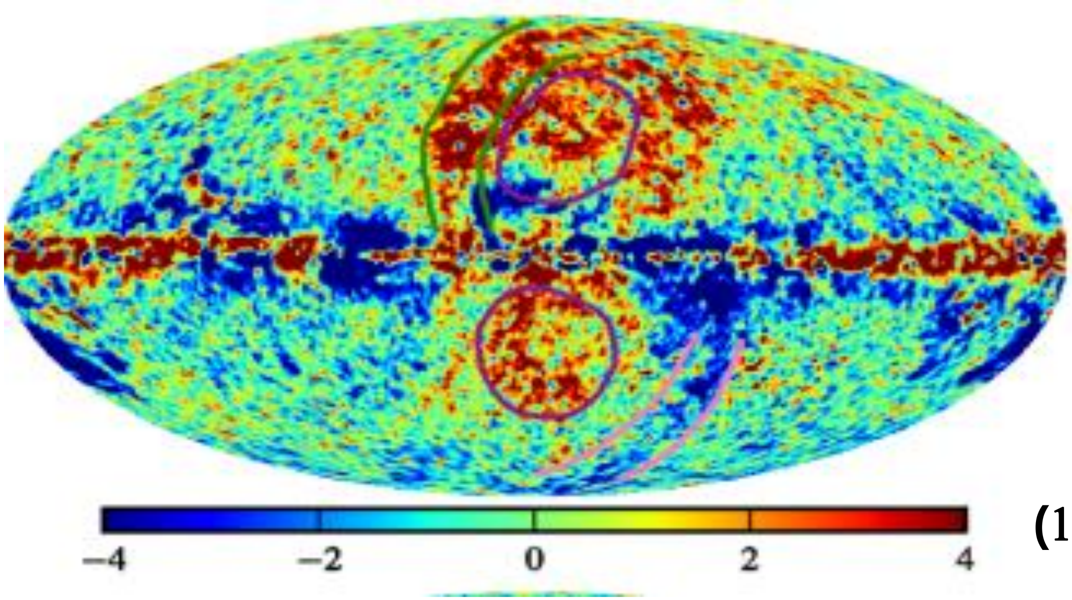
Since this is a workshop, I just thought to discuss our struggling in understanding Fermi data and hope for critical input.

No definite conclusions at present!!

Comparison of Fermi data with the GALPROP Galactic Model

FERMI-LAT OBSERVATIONS OF THE DIFFUSE γ -RAY EMISSION: IMPLICATIONS FOR COSMIC RAYS AND THE INTERSTELLAR MEDIUM, ApJ. 750,arXiv:1202.4039

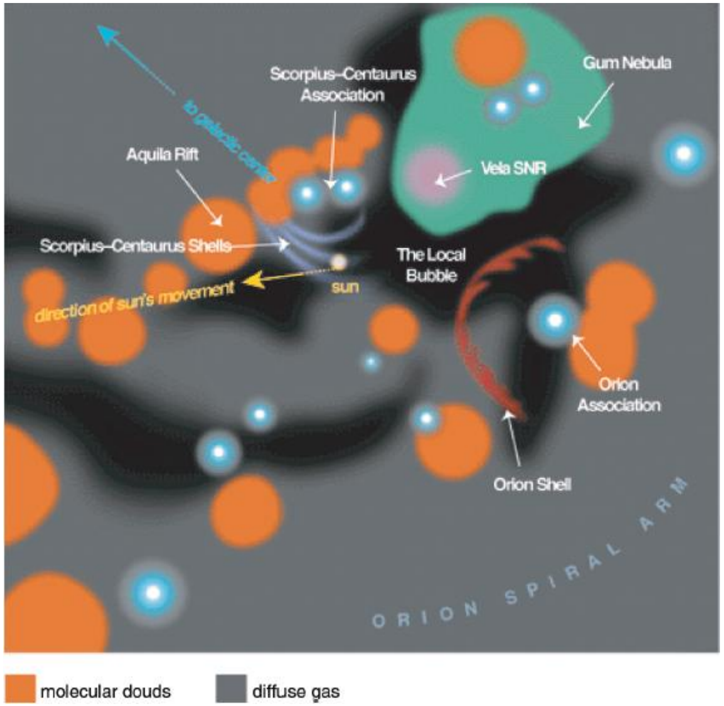
Residuals between Galprop and Fermi data in number of standard deviations



($1\sigma \approx 10\%$)

Background templates usually taken from Galprop, which requires local CR spectra to be described.
Since we are in rather special environment (Local Bubble), this requirement is questionable!

Local Bubble



Our sun is located in VERY underdense region of gas, called the local bubble (void). (probably caused by SN explosion(s). Gehrel, Nature 361 (1993)705; doi:10.1038/361706a0)

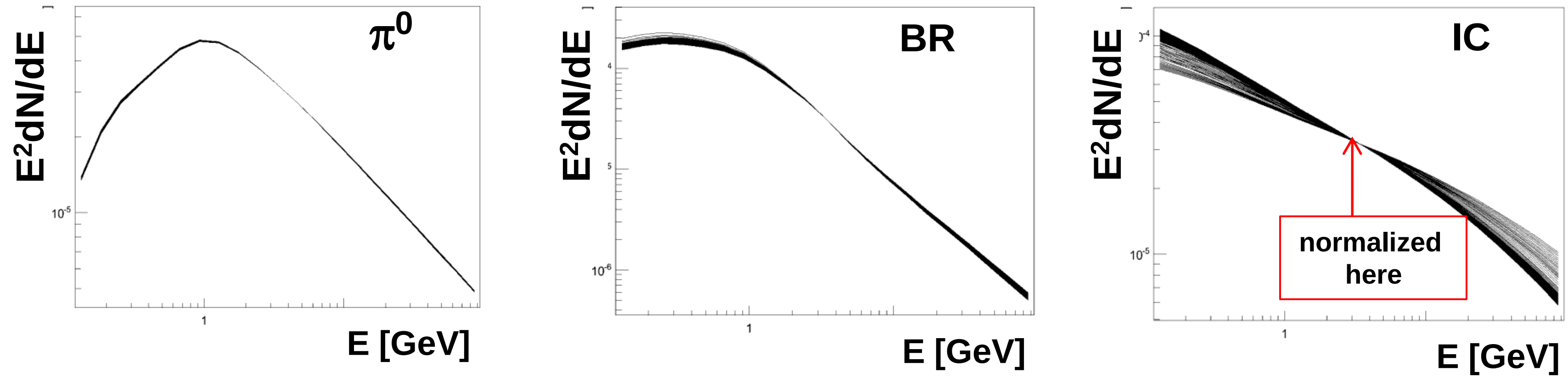
Different diffusion coef. , chimney like magnetic structure near walls, and solar modulation can change CR spectrum locally.

So CR spectrum needed for gamma rays may differ somewhat from locally observed spectra.

From: *SOLAR JOURNEY: THE SIGNIFICANCE OF OUR GALACTIC ENVIRONMENTFOR THE HELIOSPHERE AND EARTH*, Ed. Priscilla Frisch

Background Templates

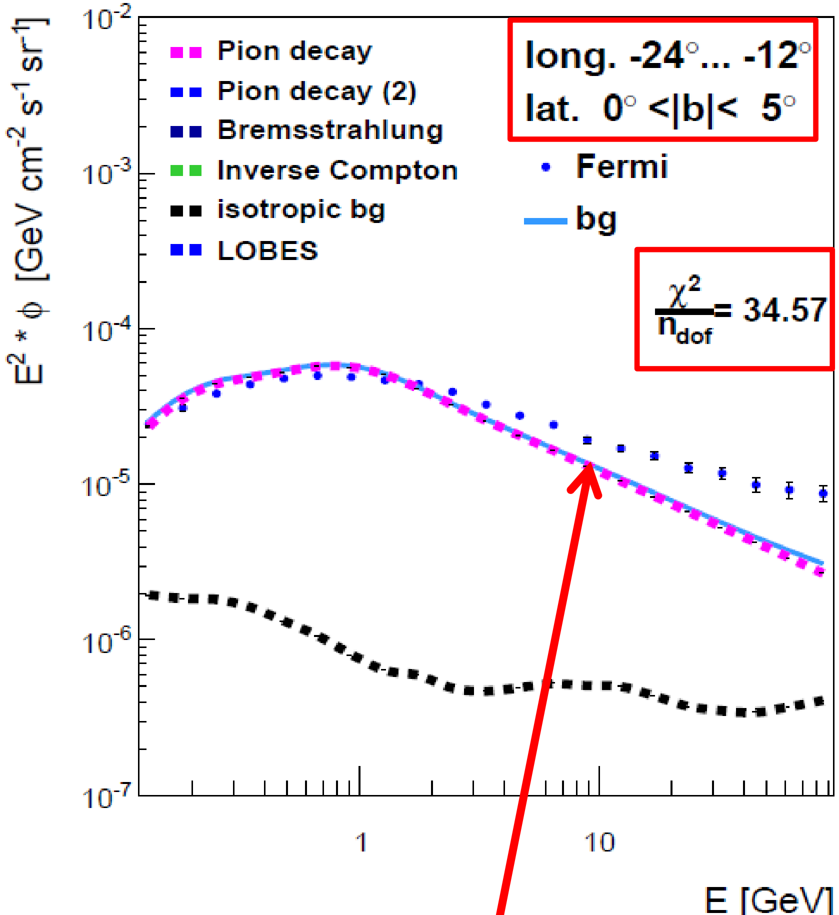
(generated by GALPROP, superimposed in l,b cones)



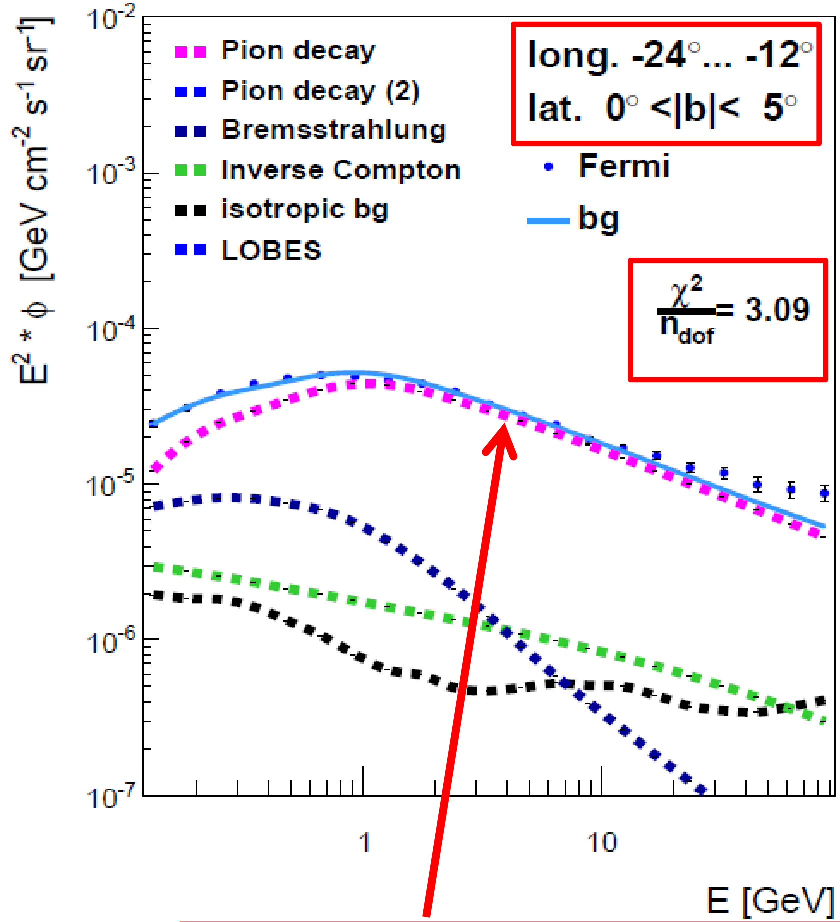
Conclusion:

- **templates similar in all directions**
- **basically only depending on CR spectral shape, if ISRF (star light, dust, CMB) difference taken into account.**
- **No need to solve diffusion-energy-loss equation with its many parameters. Just adjust CR spectra to fit Fermi data, NOT Local Bubble data.**
- **Fitting the above templates to data yields normalization of each component. Bad χ^2 would indicate missing component.**

Sensitivity of templates to CR spectrum

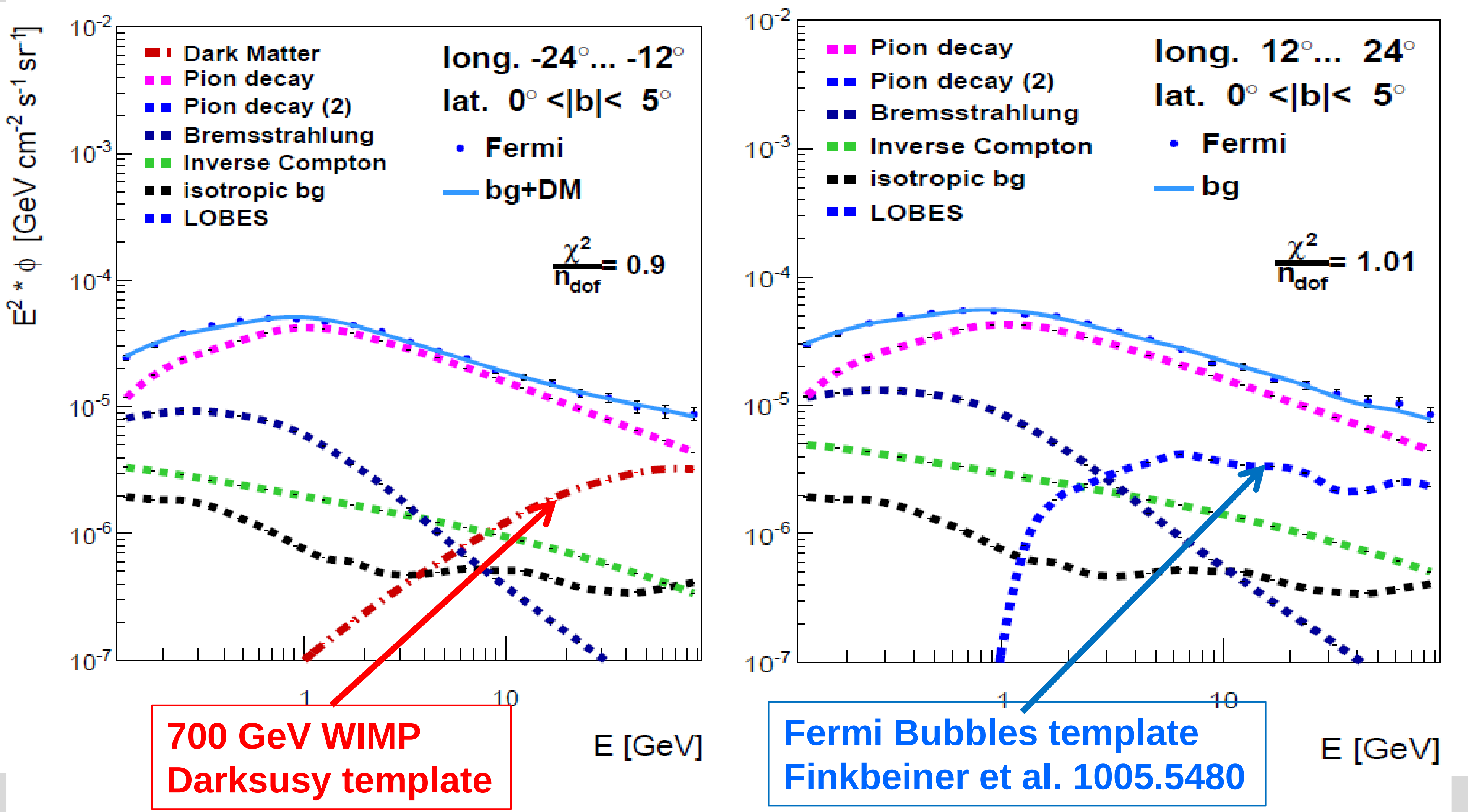


Template based on local CR spectra

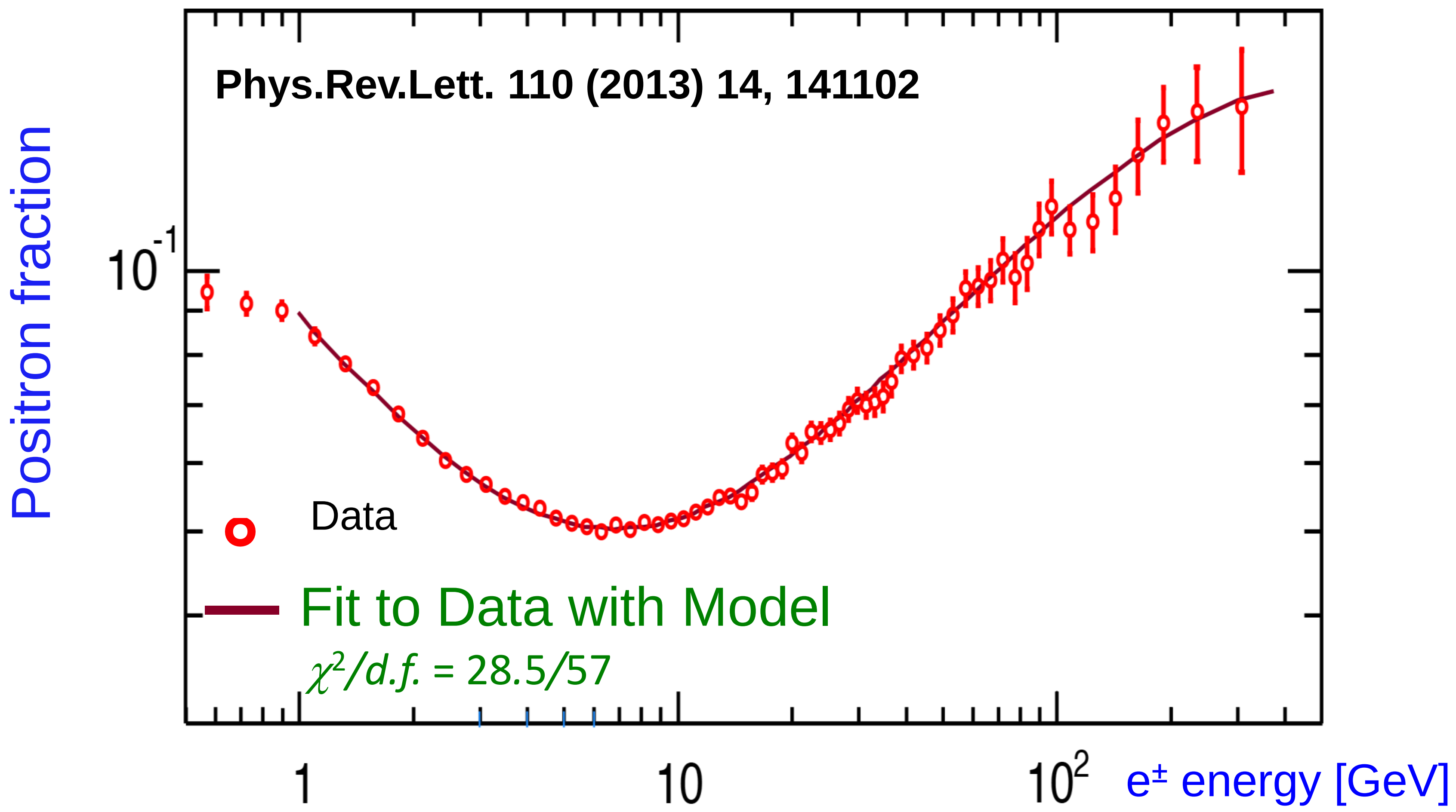


Increased spectral index of high energy CR nuclei by 0.1

Excess above 10 GeV needs hard component, if not instrumental



AMS Positron Fraction

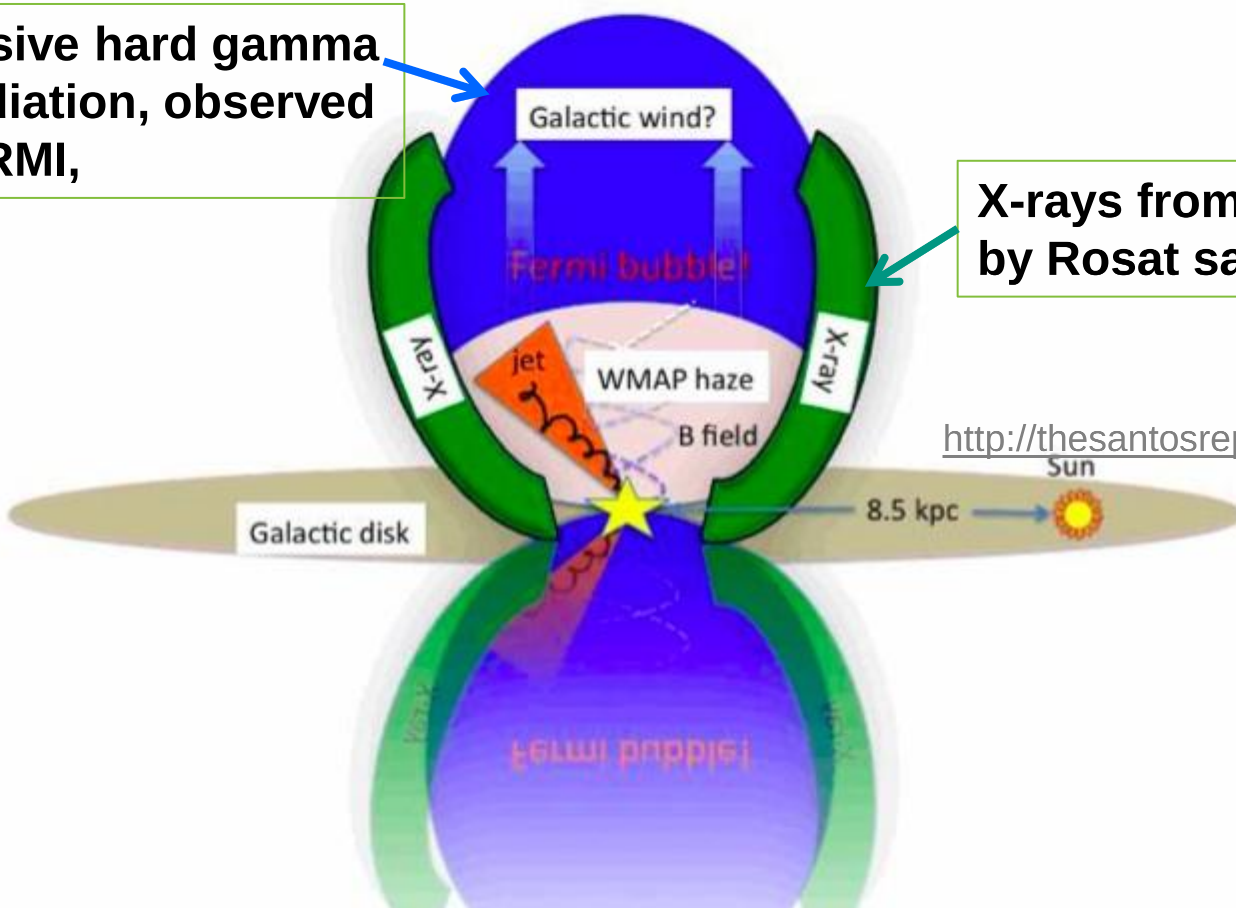


Fit requires positron source with cut-off around 750 GeV

Cartoon picture of Fermi Bubbles and Wmap Haze

Excessive hard gamma ray radiation, observed by FERMI,

X-rays from hot gas observed by Rosat satellite

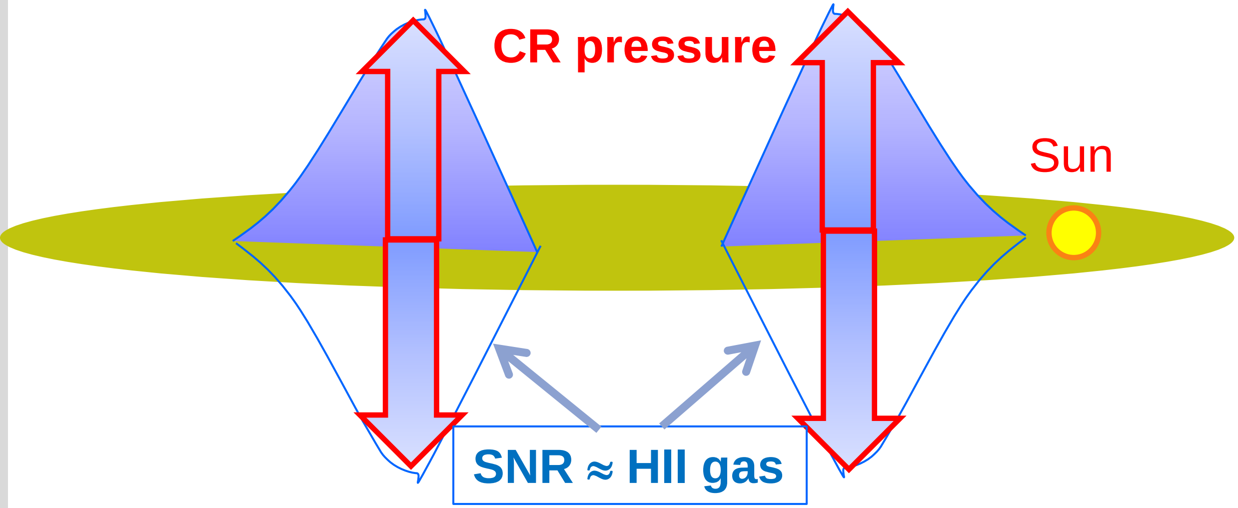


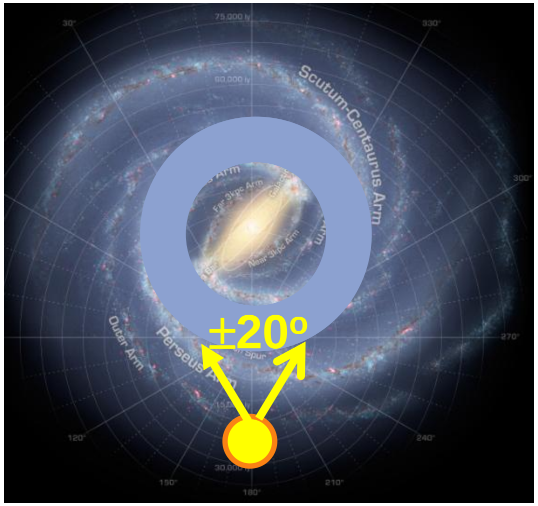
http://thesantosrepublic.com/article/119577

Common belief: Bubble originates from GC
Trouble is: electromagnetic radiation only observed along line-of-sight, NO distance information, so Bubble could be much nearer.

Alternative idea: outflow of hot gas not from GC, but DISC

(Breitschwerdt:„Blown away by CR“, Nature 452(2008)826)
(see also 0905.3071, 0905.0431)

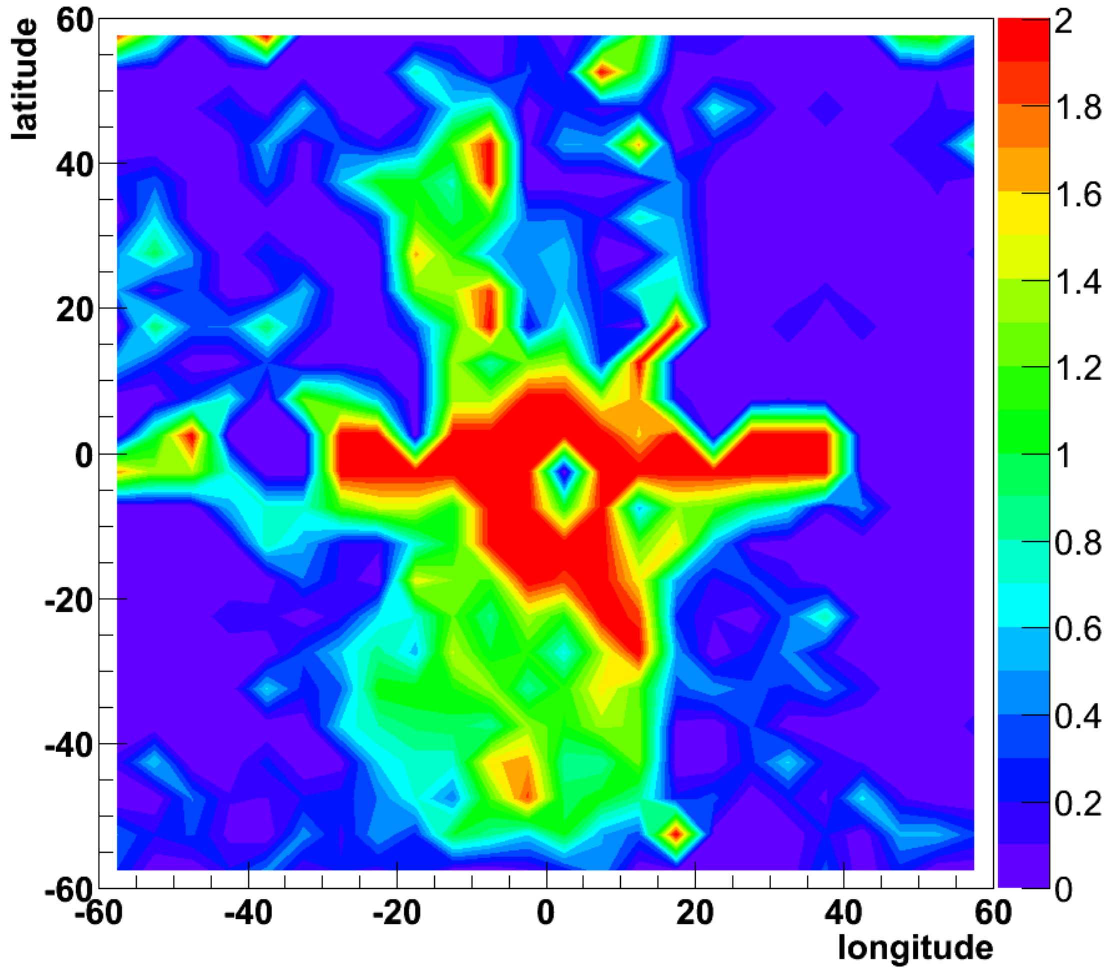


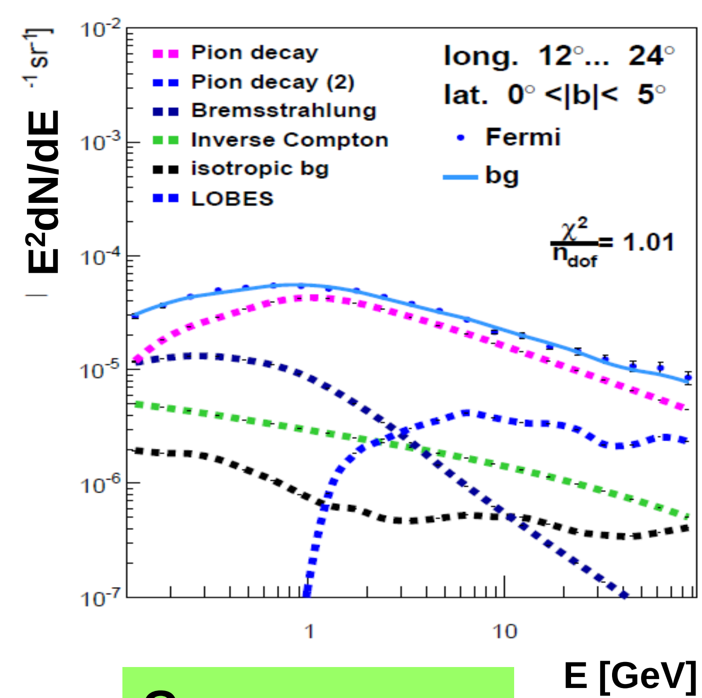


Properties of outflow by CR pressure:

- **naturally explains shape of Fermi Bubble:**
  max. towards GC
  width in longitude ±20 degrees
  width in latitude: ±50 degrees for scale height of 2 kpc
  (= revised scale height from Gaensler, et al. 0808.2550)
  outflow with frozen magnetic fields parallel to outflow leads to sharp edges
  (chimney like structures, see e.g.1109.0255, , 0905.0431)
- **distinguishable by cylinder-like instead of balloon-like shape of bubble??**

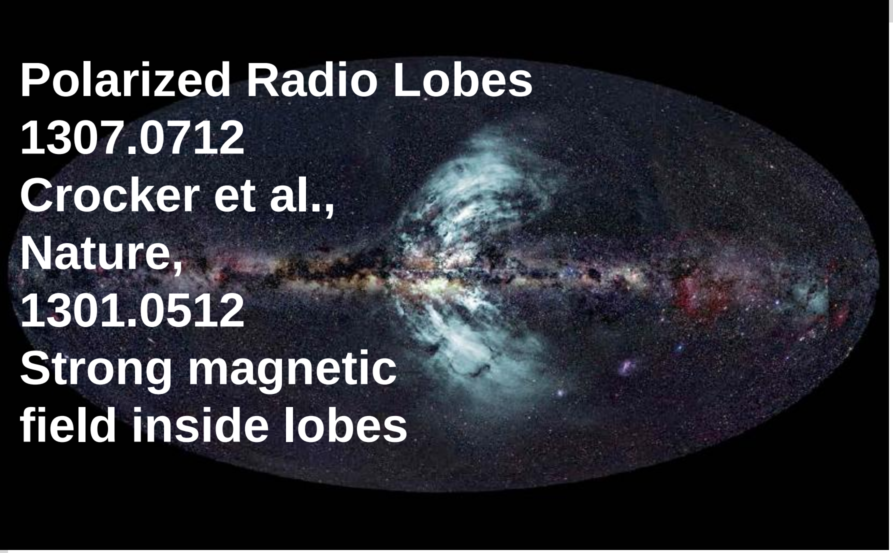
Fermi Bubble from template fit to Fermi data

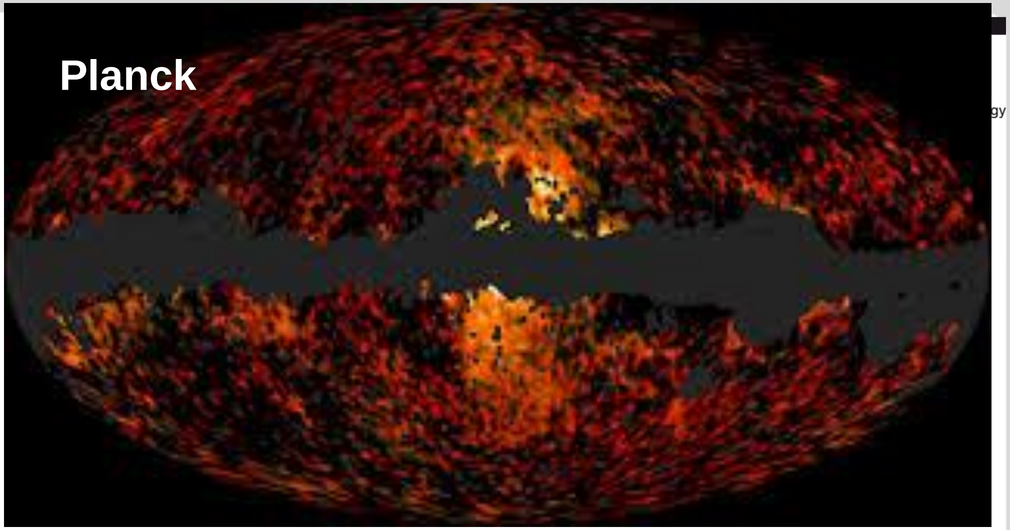


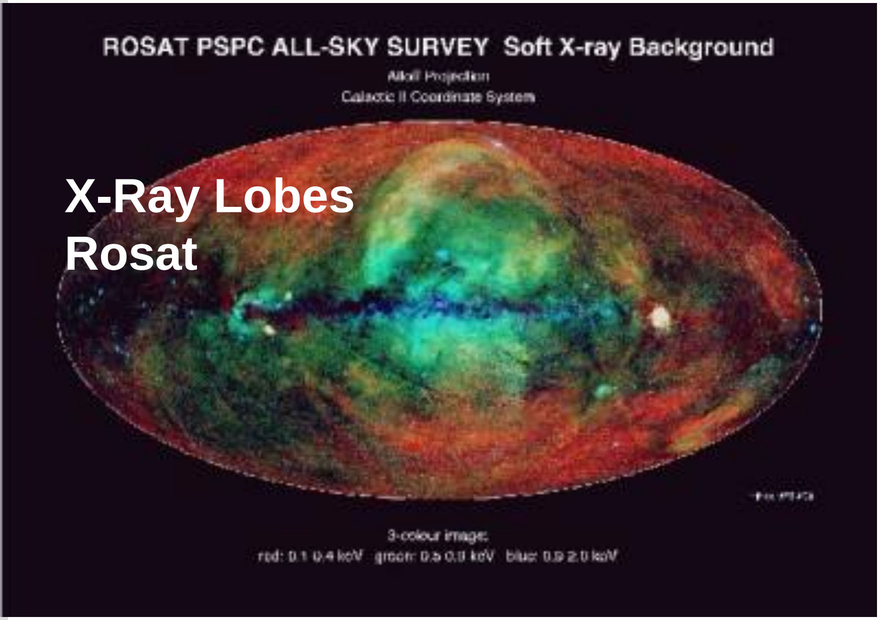


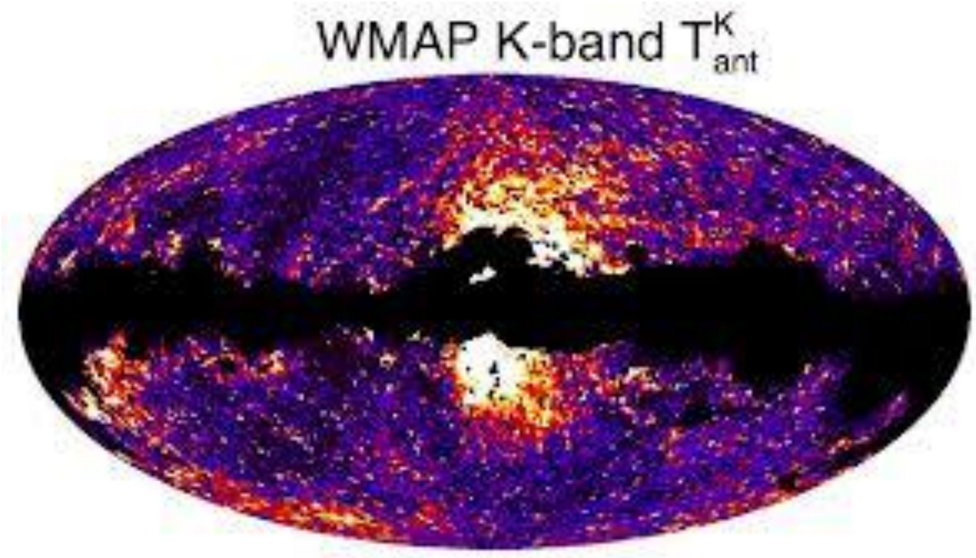
Green means identical flux as Finkbeiner et al. 1005.5480

Data shows BROAD base of Fermi Bubble in Galactic plane
Provides evidence that FERMI Bubble is NOT ONLY from GC


Polarized Radio Lobes
1307.0712
Crocker et al.,
Nature,
1301.0512
Strong magnetic
field inside lobes

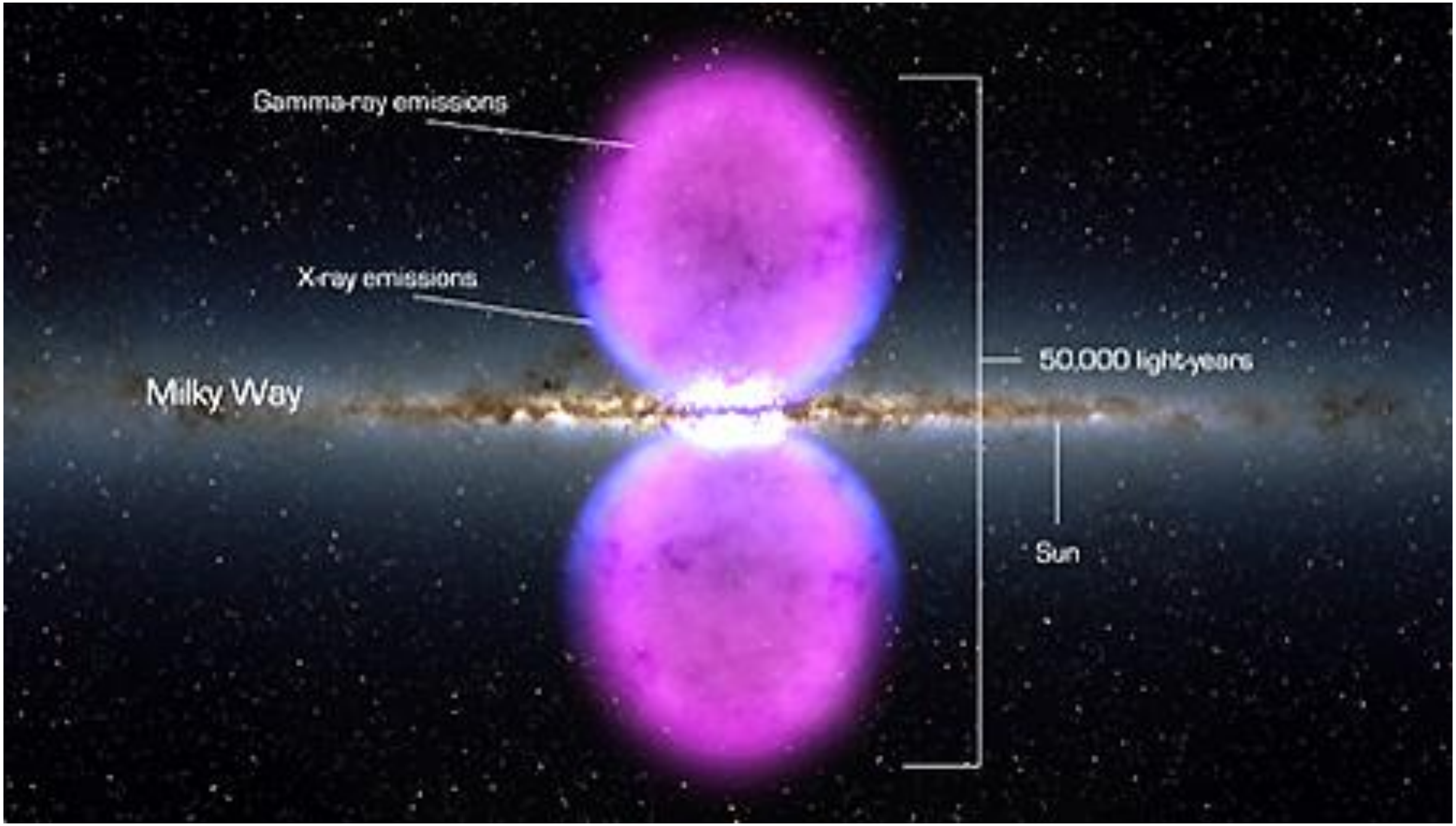

Planck


ROSAT PSPC ALL-SKY SURVEY Soft X-ray Background
X-Ray Lobes
Rosat


WMAP K-band T^K_{ant}

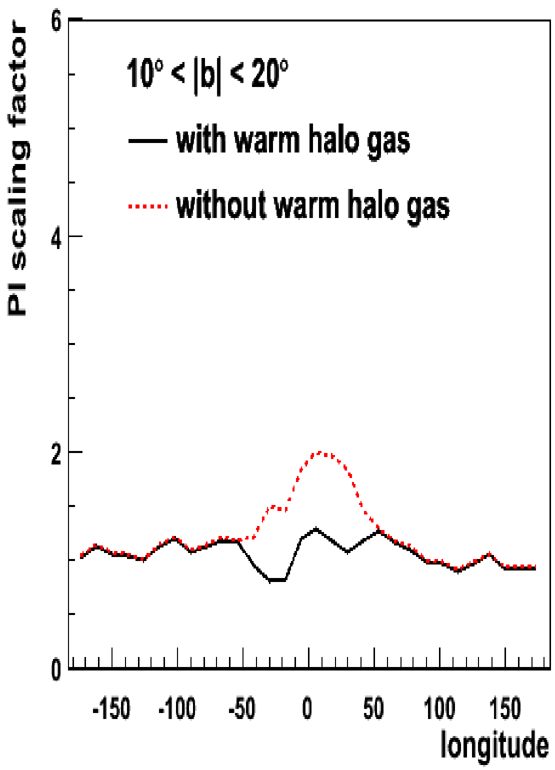
Quite different from 2010 NASA picture of Fermi Bubble

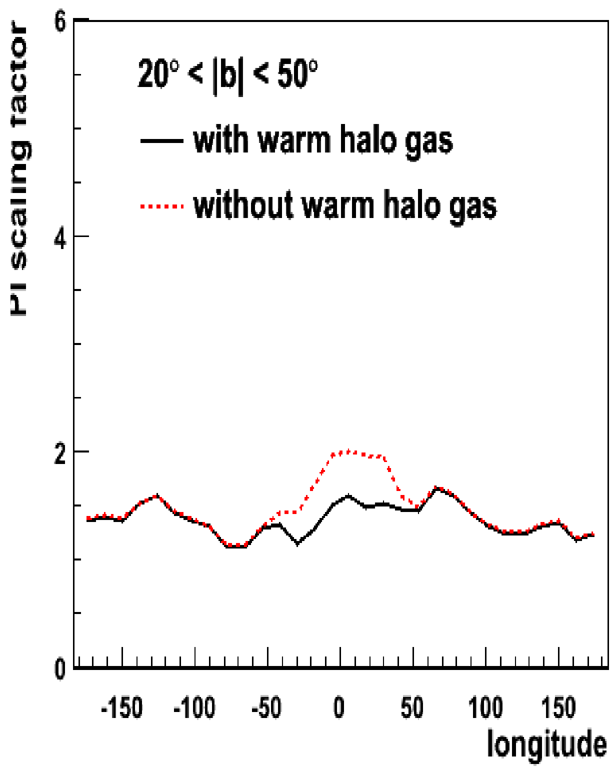
http://www.outerspacecentral.com/mw_haze_page.html



Bubble Comparison with GALPROP

- Simulate Fermi Bubble as cylinder-like HII gas in Galprop
- Check if emissivity in halo is reproduced





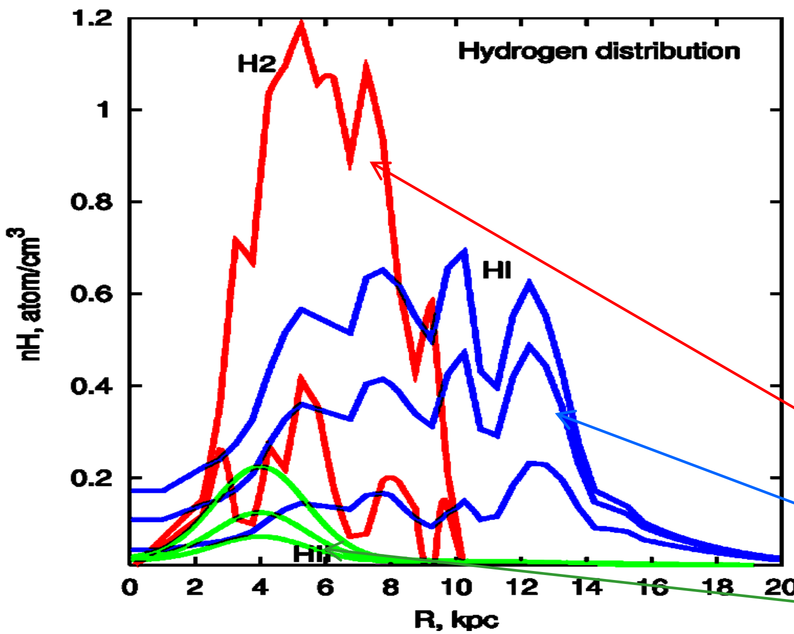
Observe:

Get flat distribution of normalization as fct. of longitude after including warm gas.

So HII gas with scale height of 2 kpc yields expected emissivity in halo.

Modification to Gas Distribution in Galprop

Galprop



3 curves at different z
highest curve at z=0

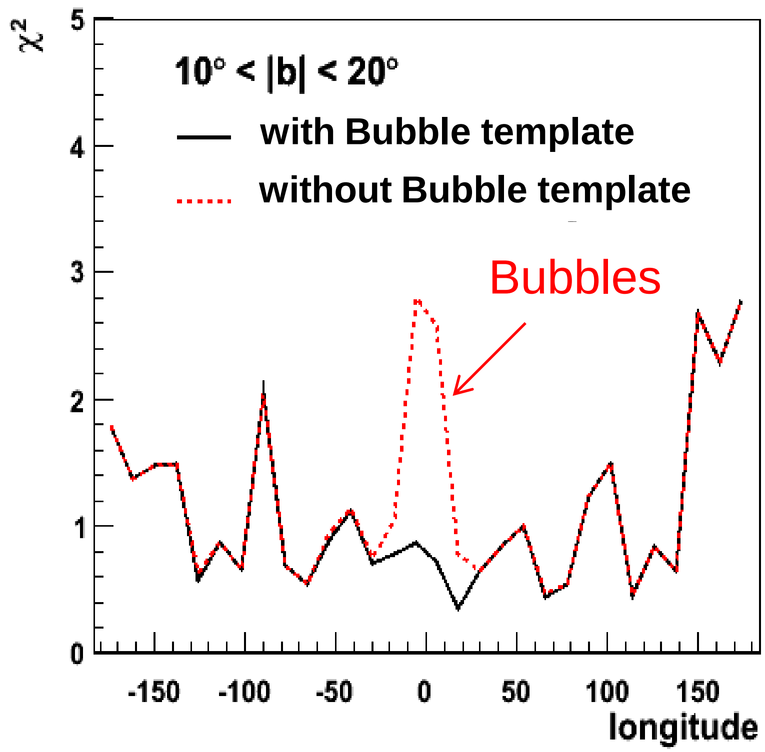
Increase scale height of warm ionized component (HII) from default of ca. 0.3 kpc (thin disc) to 2 kpc (from revised scale height by Gaensler et al., 0808.2550: "The Vertical Structure of Warm Ionised Gas in the Milky Way")

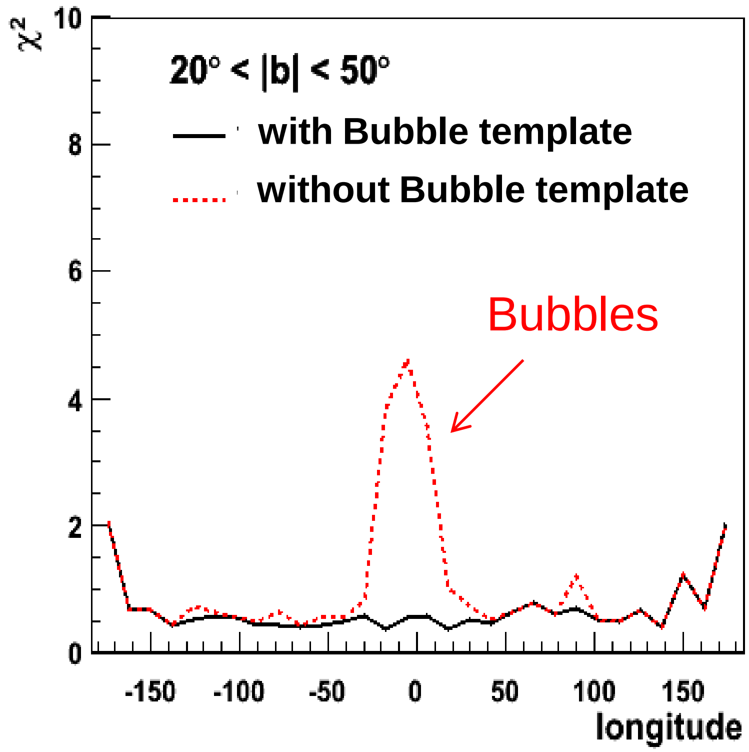
H2: H-molecules (traced by CO line)

HI: H-atoms (traced by 21 cm line)

HII: Warm ionized H-gas (traced by e)

χ^2 with and without Fermi Bubble Template



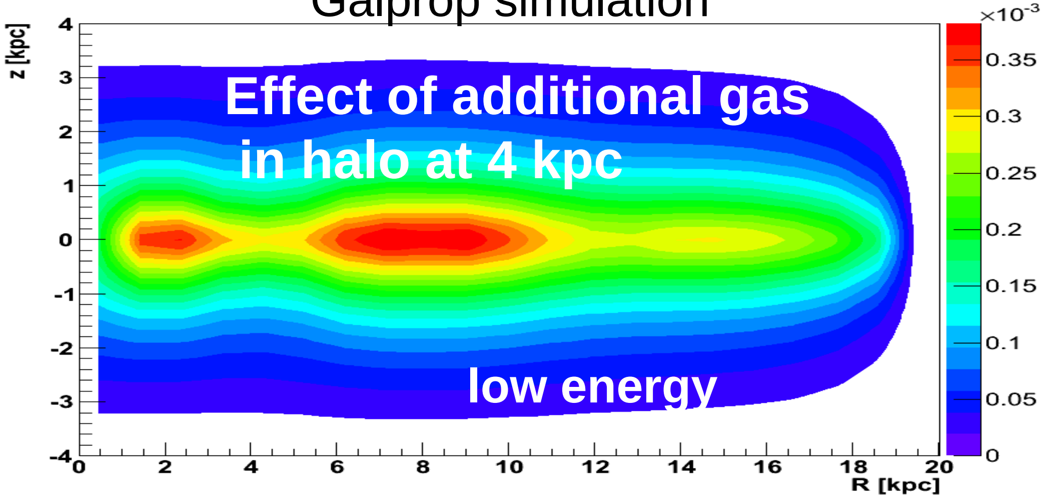


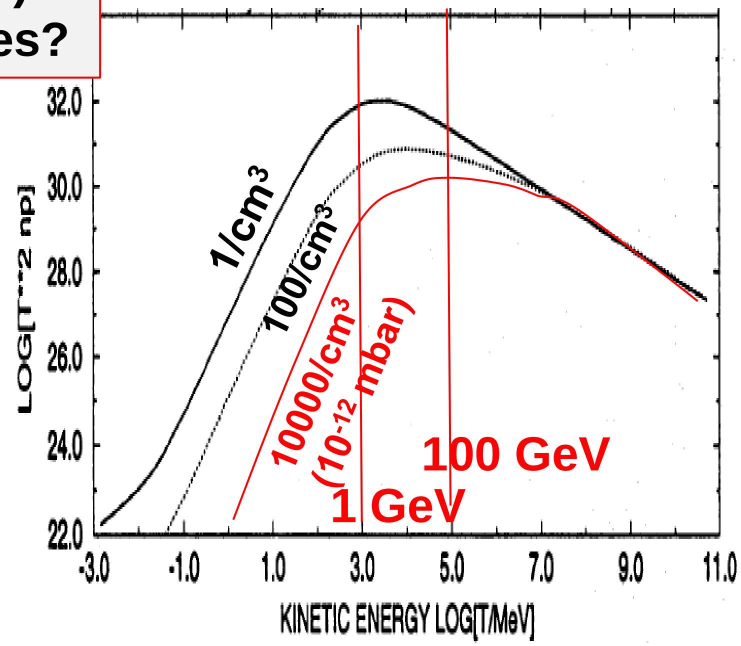
χ^2 smooth in longitude after including Bubble template

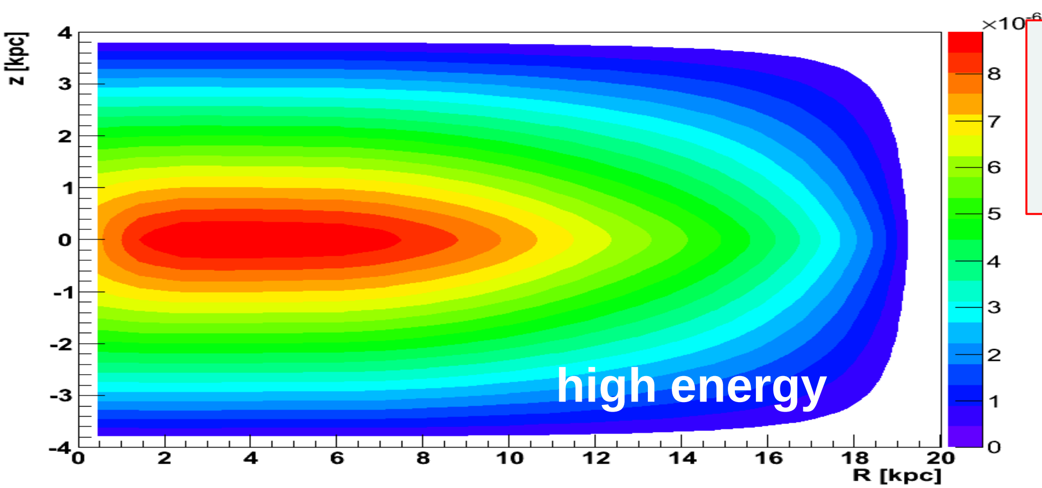
Why harder Spectrum for Fermi Bubble?

1) Significant non-eq. „fresh“ CR comp. ($1/E^2$)?
2) Flattened CR spectrum by ionization losses?

Galprop simulation







Ionization losses flatten CR spectra below 100 GeV
(Mannheim, Schlickeiser, A&A 286 (1994) 983)

Outflow may alleviate large bulge/disc ratio of positron line

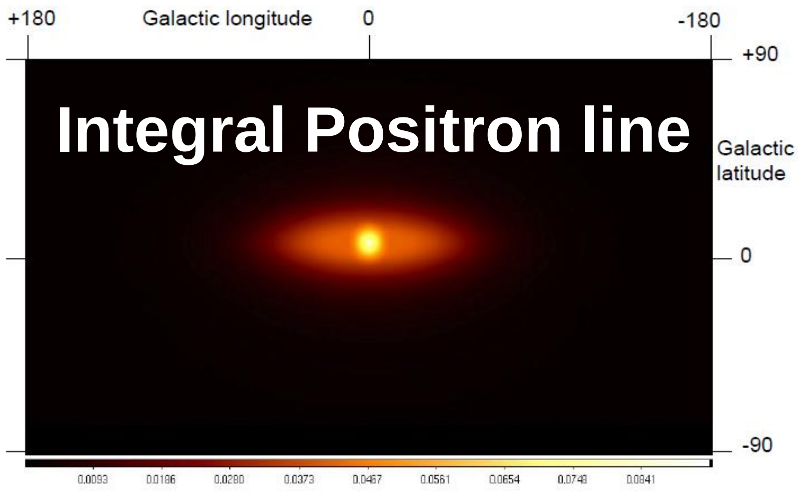
Sources of low energy positrons:

radioactive nuclei from SNR and other stellar objects, see Prantzos, Diehl, Physics Reports 267 (1996) l-69. Prantzos et al., 1009.4620

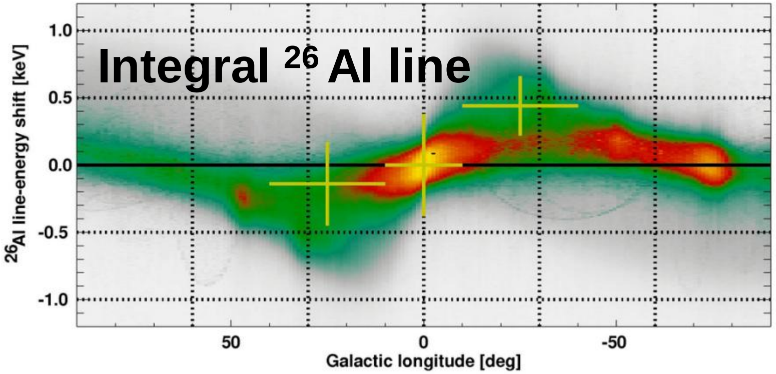
bulge/disc ratio larger than expected for positrons

Possible explanation:

Light positrons driven into halo by CR pressure, heavy nuclei stay in disc



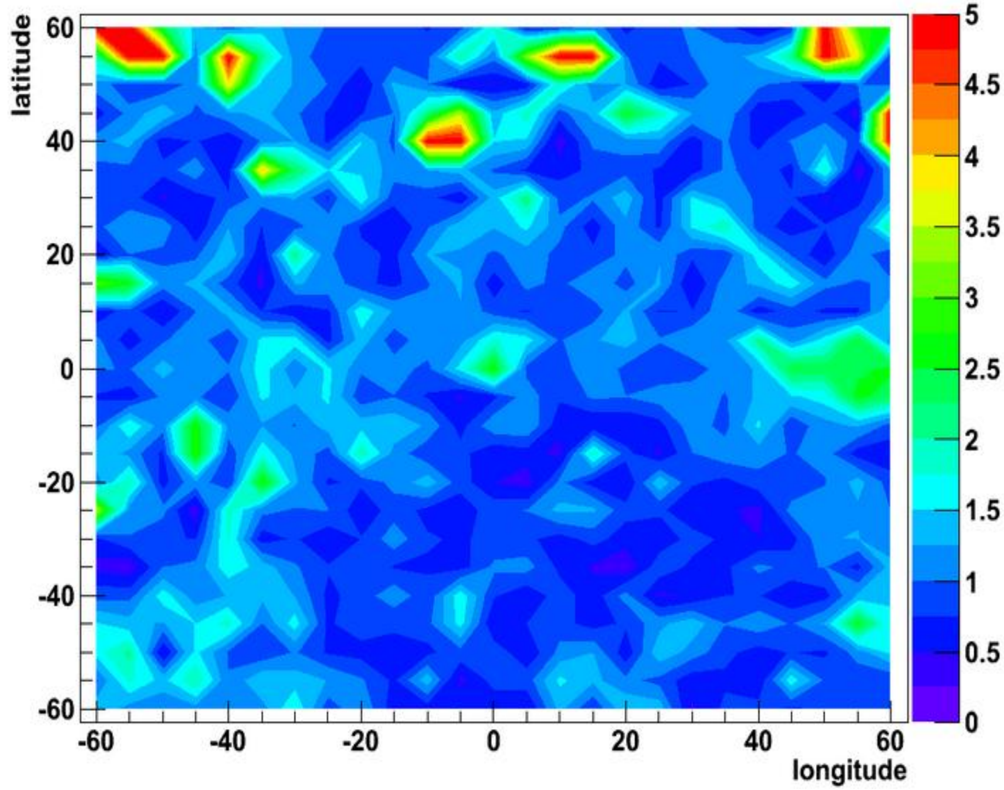
simple model fit to Integral/SPI data



Reduced χ^2 in l,b around 1 everywhere!

Karlsruhe Institute of Technology

Remind: template fit
with modified proton spectrum
and including Bubble template



Have now excellent description of diffuse gamma ray sky with absolute normalizations of each component as expected.

No need for DM sofar.

Good description allows to set limits on DMA signal.

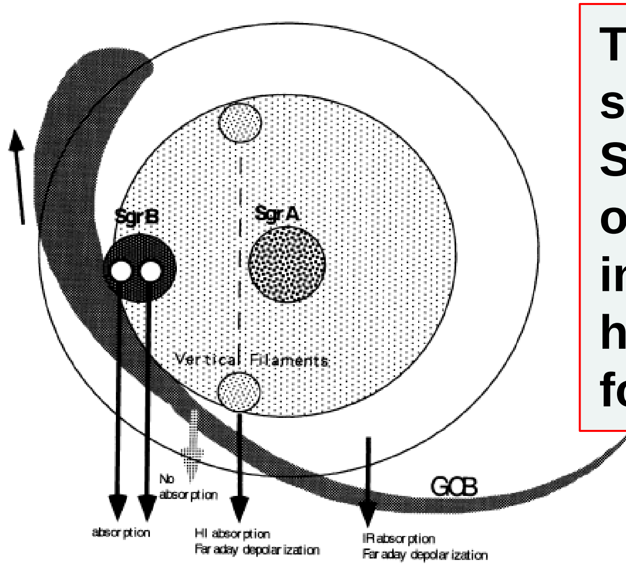
Consider two regions for DM searches:

1) Galactic Center within few degrees
2) Inner Galaxy (|l|<62.5^o |b|<62.5^o)

1) A closer look at inner degree of GC

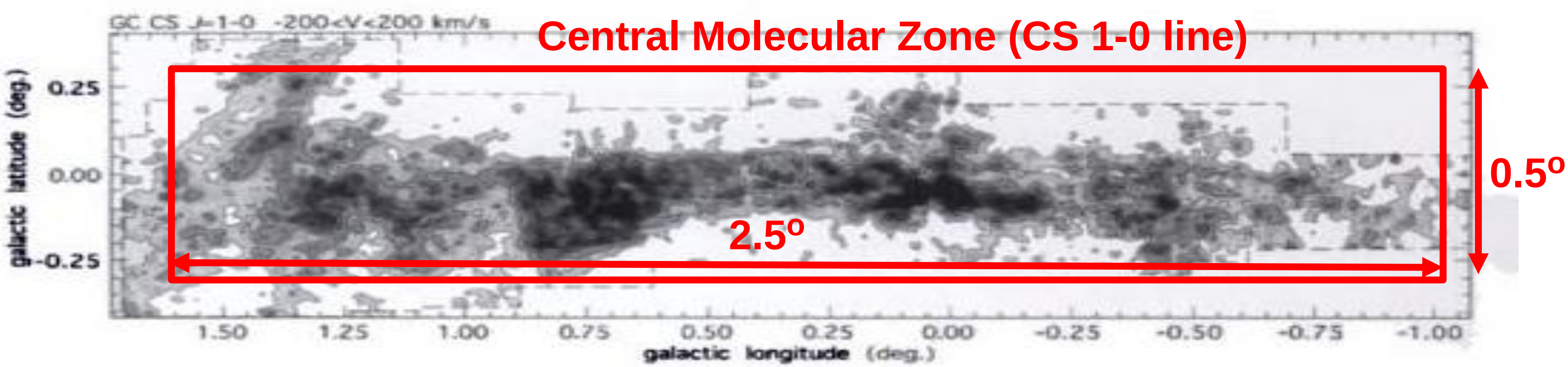
Accretion disc of SMBH has ≈5.10^{7}M$_\odot$ of cold gas in inner 1^o

BH: 4.10^{6}M$_\odot$
Gas: 5.10^{7}M$_\odot$
Density: 10^3-10^4 /cm^3



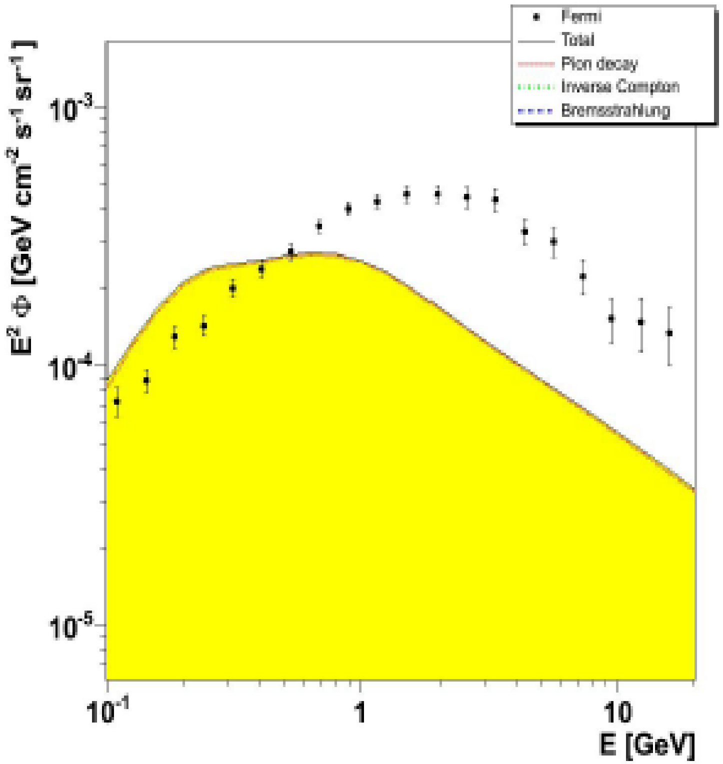
Tidal forces ∝ 1/r^3, so very strong near SMBH ⇒ streams of molecular gas interspersed with hot gas from star formation and SNR

45 m Radio Telescope, Tsuboi et al., ApJS 120(1999)

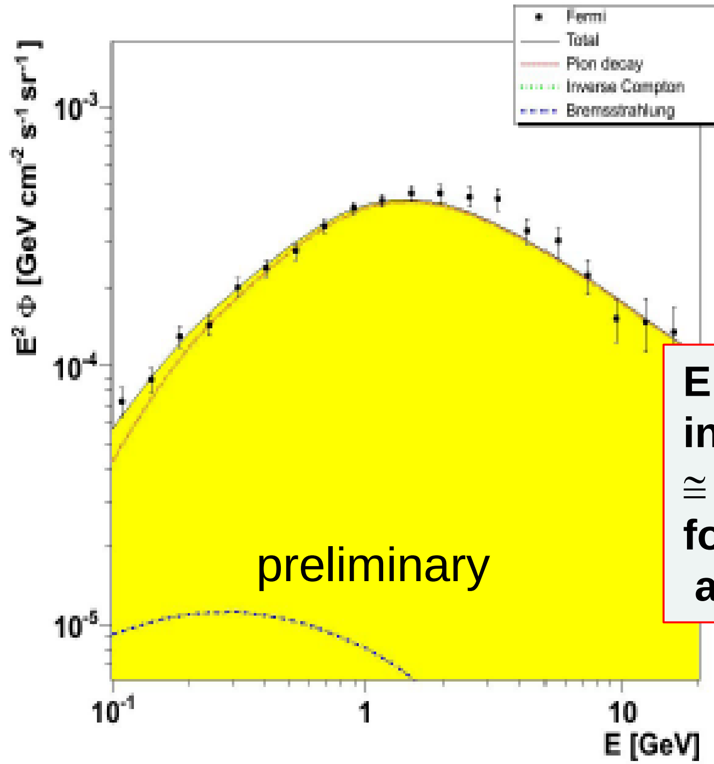


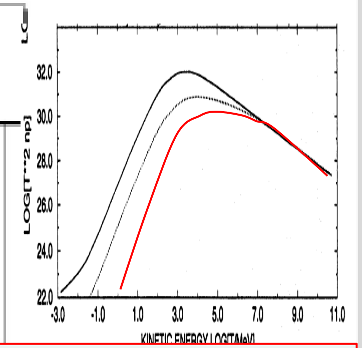
Inner 1° of GC without/with dense gas

Conventional Galprop



Flattened proton injection spectrum





Energy loss time in molec. cloud ≅ diffusion time for 100 pc cloud at 10 GeV

Ad hoc, but physically motivated tuning of proton injection index, allows to describe gamma spectrum from GC as alternative to DMA.
Correct?? Anyway, comparison between inner 1° and surroundings should take high density gas in CMZ into account

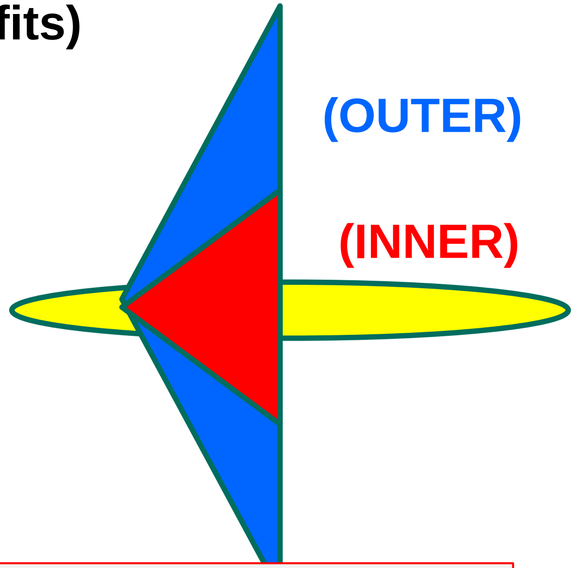
2) A closer look at 60 degree around GC

Comparison of 625 directions

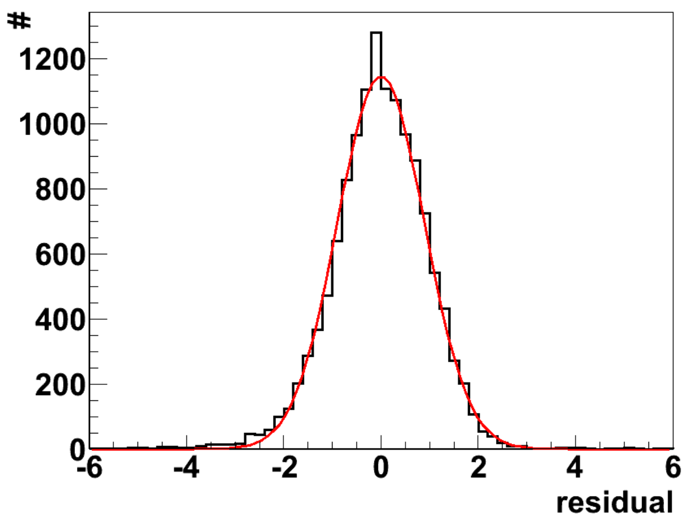
Divide sky in 625 cones of 5x5 degree towards inner Galaxy:
(most sensitive to DM and well described by template fits)

Longitude: $-62.5<l<62.5$: 25 bins (TOTAL)
Latitude: $-62.5<b<62.5$: 25 bins

Subdivide latitude in 2 regions to check consistency:



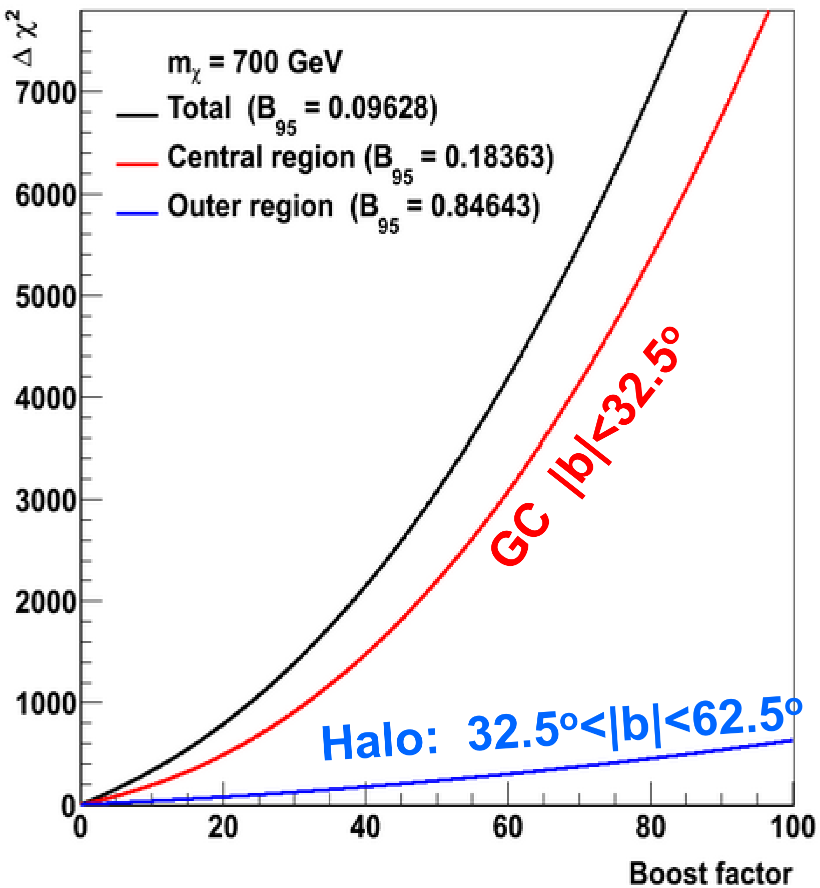
Latitude: $32.5<|b|<62.5$: 25 bins (OUTER)
Latitude: $-32.5<b<32.5$: 25 bins (INNER)



Errors in large 5x5 degree cones dominated by syst. errors (taken from http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html)

Residuals have Gaussian distribution. Can simply use $\Delta\chi^2=2.7$ to get 95% C.L. for signal strength after profiling the normalizations of each template.

Upper limit on boost factor for 700 GeV WIMP



625x21 =13125 data points
Reduced χ^2=1.01 after excl.
8% „bad regions“
95% C.L. $\Delta\chi^2$=2.7

Upper limit on < σv>=2.8.10^{-26} cm^3/s for 700 GeV neutralino:

95%CL upper limit on DMA signal:

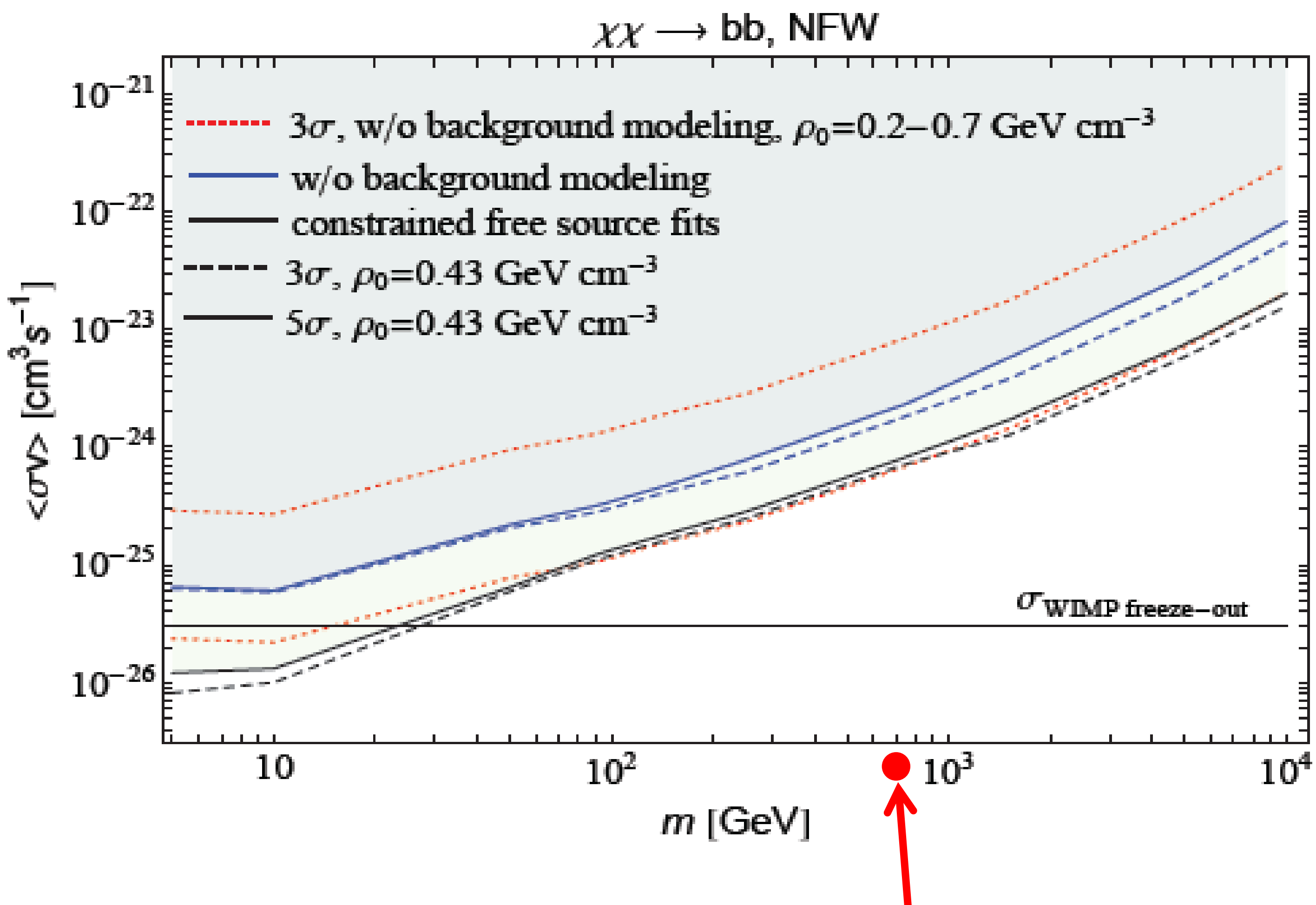
0.1< σv>= 2.8.10^{-27} cm^3/s

so below annihilation cross section needed for WMAP relic density

Most of sensitivity comes from GC region, as expected.

Similar results for different DM profiles, since cuspy region has small solid angle

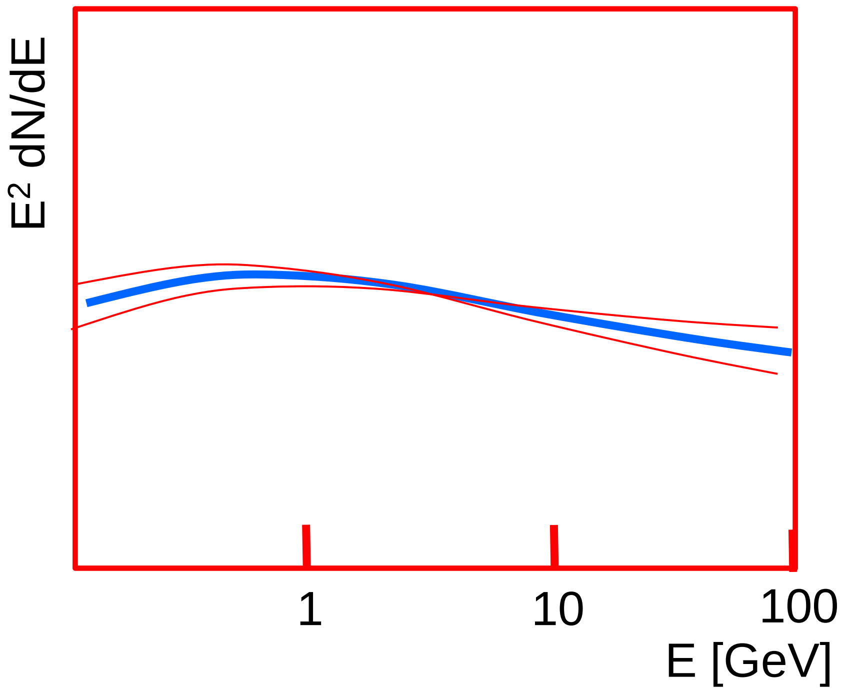
Comparison with Fermi publ. ,arXiv:1205.6474v2



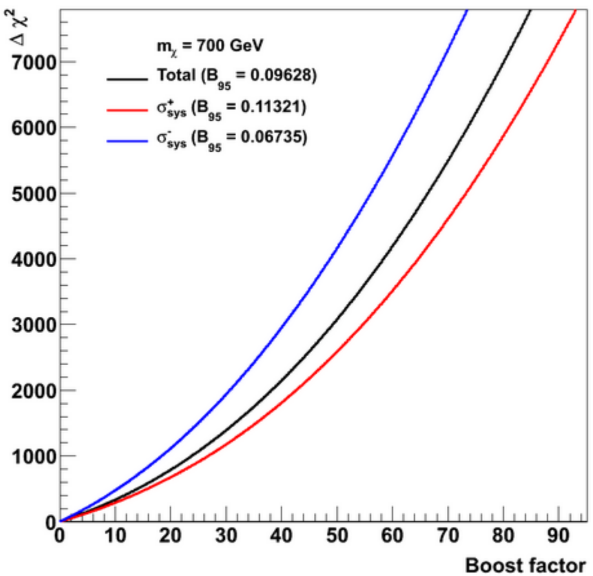
Our PRELIMINARY result using model with ≈12000 data points and χ^2/dof≈1 including GC region

How to handle correlations between data points?

Consider extreme cases: Allow max. deformation of shape by lowering high energy by 1σ and increasing low energy by 1σ and vice versa, as indicated by red lines around central value



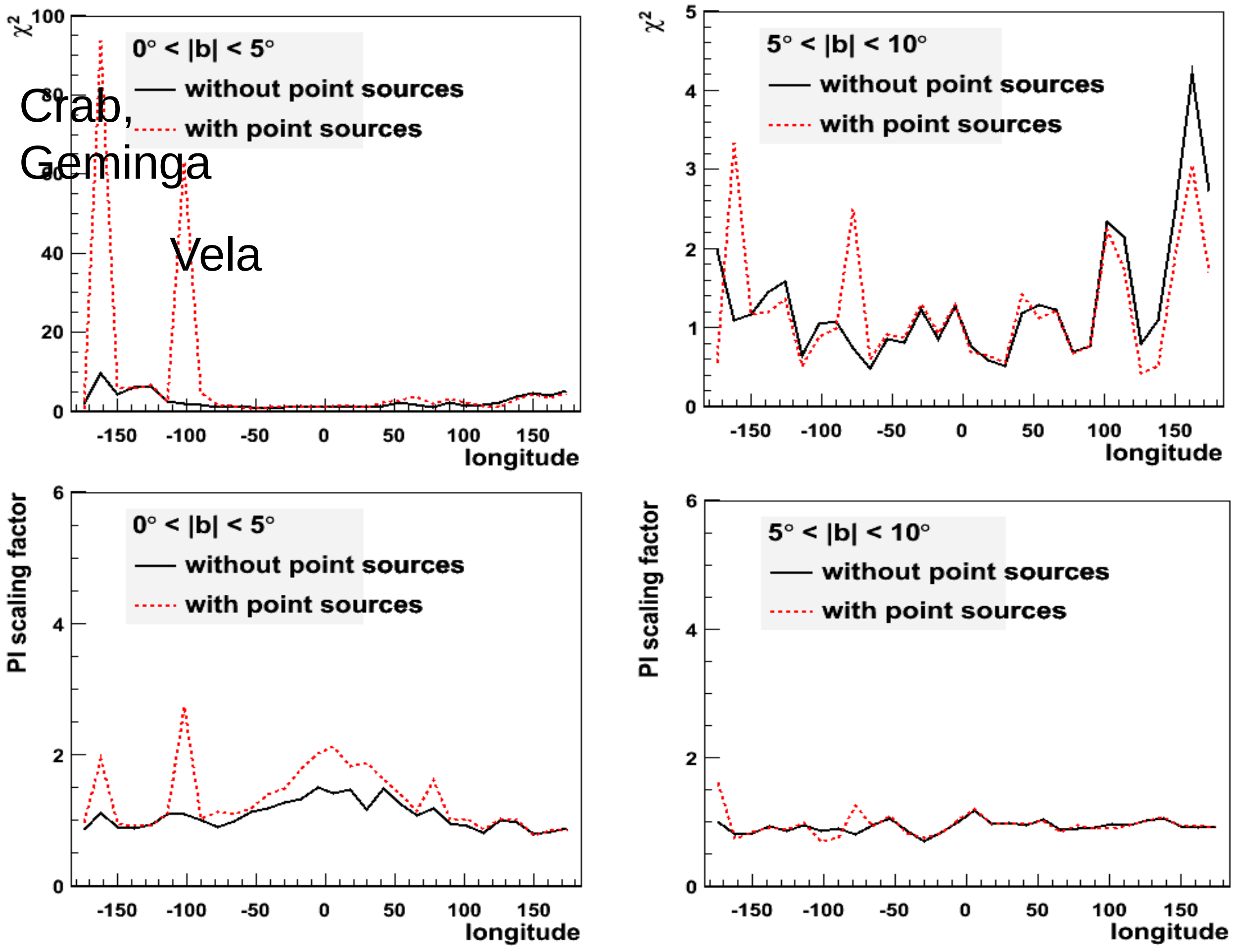
$B_{95\%C.L.}$=0.10 ± 0.02



**Uncertainty in shape of data yields 20% uncertainty on upper limit
This dominates all other uncertainties, like uncertainties from point sources, background, template uncertainties, etc.**

Effect of point sources

Compare raw data with diffuse data plus point source subtraction

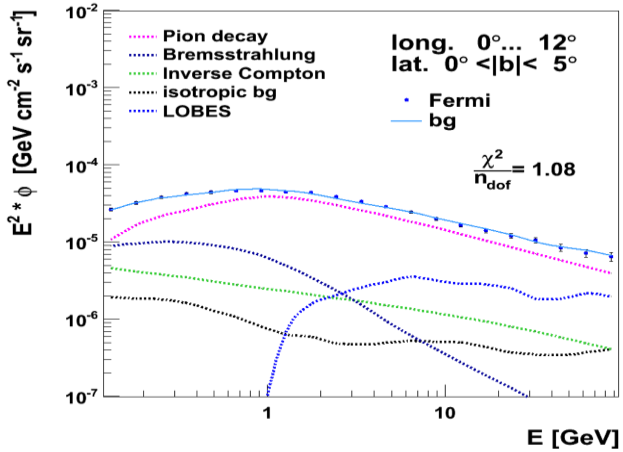


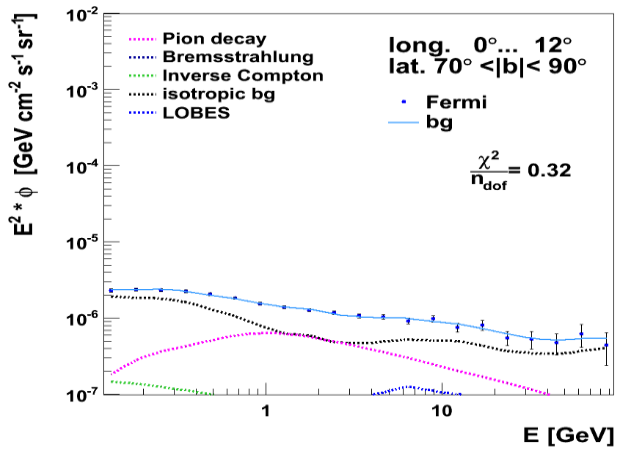
1) point sources minor influence for large bin size

2) Can either subtract point sources (second catalogue) or make cut on reduced $\chi 2$ to remove regions with strong point sources

3) Limits practically independent of method.

Effect of background





Nuclei not firing the veto counter, having correct dE/dx and an electromagnetic shower are misidentified as a photon.

However, since this background is isotropic, it is absorbed in the template for isotropic background and mainly significant for the pole regions, where it describes the data well.

Template taken from Fermi team for diffuse class background.

Isotropic template normalization well constrained by fit.
Background small contribution for inner Galaxy

Summary

- Template fit to 4 yrs FERMI data in 625 sky directions ($5x5^o$) yields everywhere excellent fits , if template for Fermi Bubbles and π^0 template corresponding to slightly harder proton spectrum than locally obs. are included).

- Good fit in all directions allows to set stringent upper limits on DMA

- Fermi Bubble template shows broad base in plane $\Rightarrow$ cylinder-like instead of balloon-like bubble from GC, so additional strong contribution from SNR between 2 and 6 kpc likely.

- Also GC inner degree spectrum may be explained by standard processes, if one assumes flattening of CR by ionization losses in Central Molecular Zone ($3\text{-}7.10^7 M_\odot$ with densities of 10^4 atoms/cm^3)