Gamma ray astronomy above 100 TeV and the ICECUBE results

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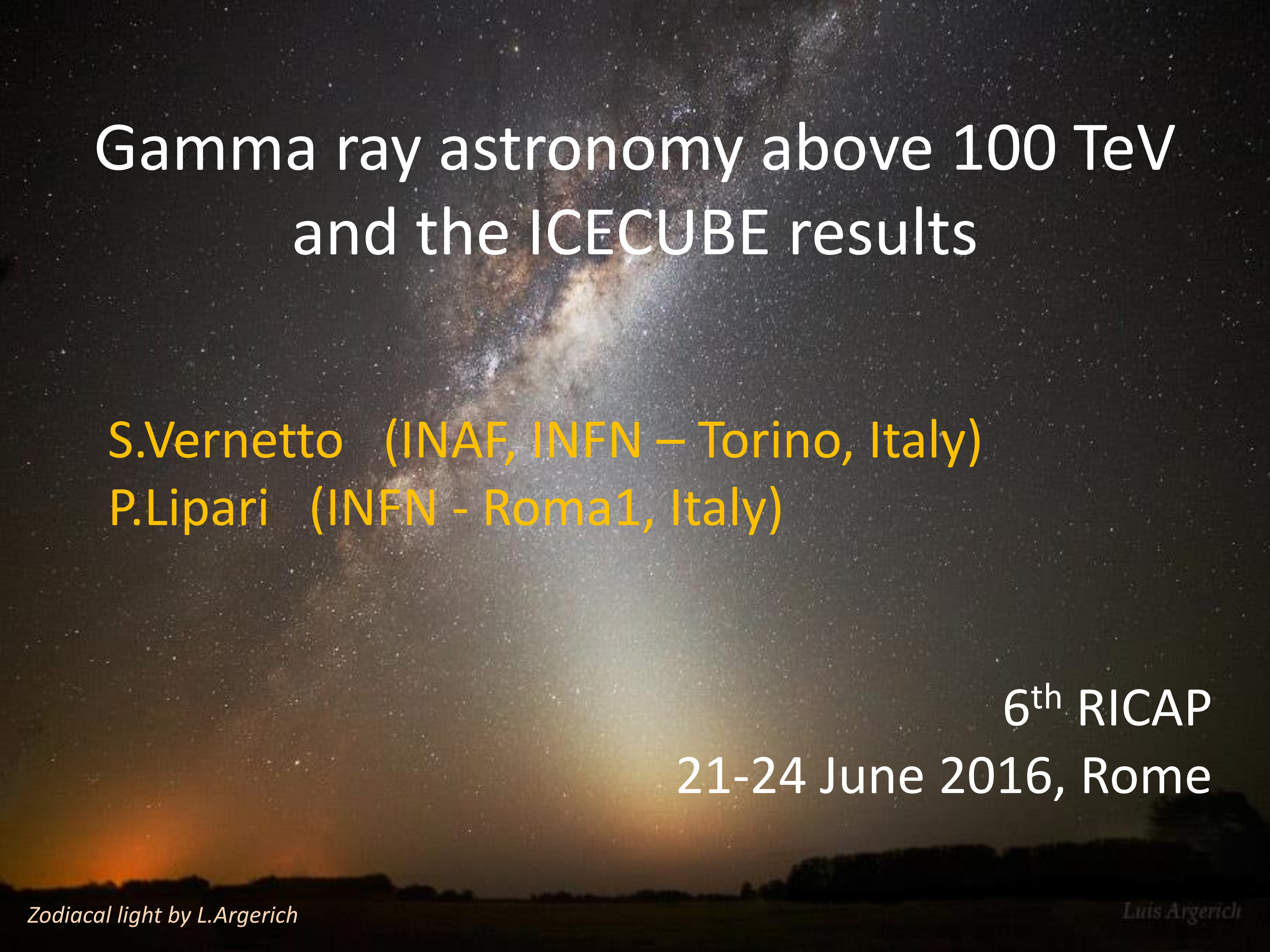
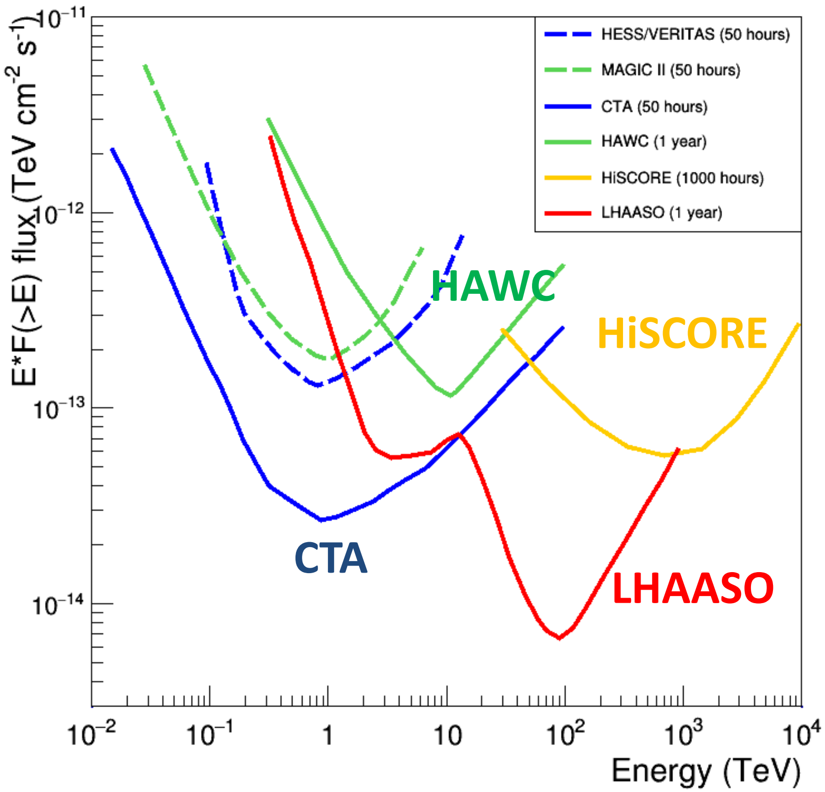


Zodiacal light by L.Argerich

Gamma ray astronomy at E ≥ 100 TeV ?

Integral point source sensitivity



Galactic astronomy:

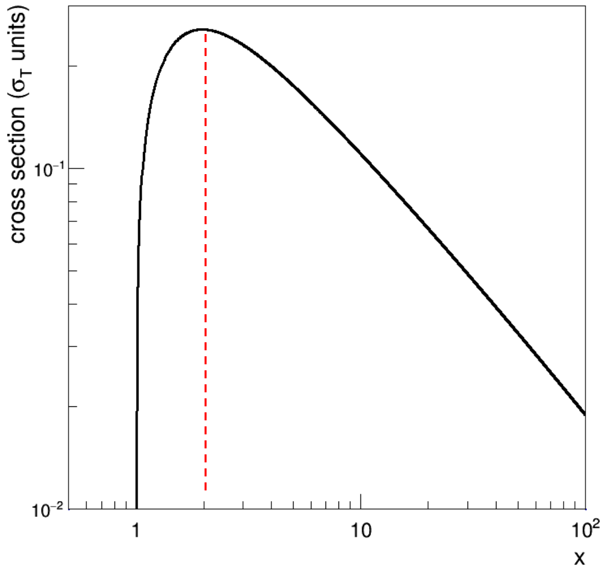
1) Point sources (SNRs…)
2) Diffuse fluxes
   (by detectors with large FOV, like HAWC, LHAASO, HiSCORE…):

   - γ-rays from c.r. interactions
   - γ-rays associated to the ICECUBE neutrinos ?

Absorption of gamma rays in the Galaxy: how much it affects the measurements ?

Attenuation of the gamma ray flux by pair production $\gamma + \gamma \longrightarrow e^+ e^-$

Cross section



$$x = \frac{s}{4me^2} = \frac{E_\gamma \varepsilon\,(1 - cos\theta)}{4me^2}$$

E_γ = gamma ray energy
ε = target photon energy
θ = angle between photons

Gamma ray energy threshold:

$$E_\gamma = \frac{2me^2}{\varepsilon\,(1 - cos\theta)}$$

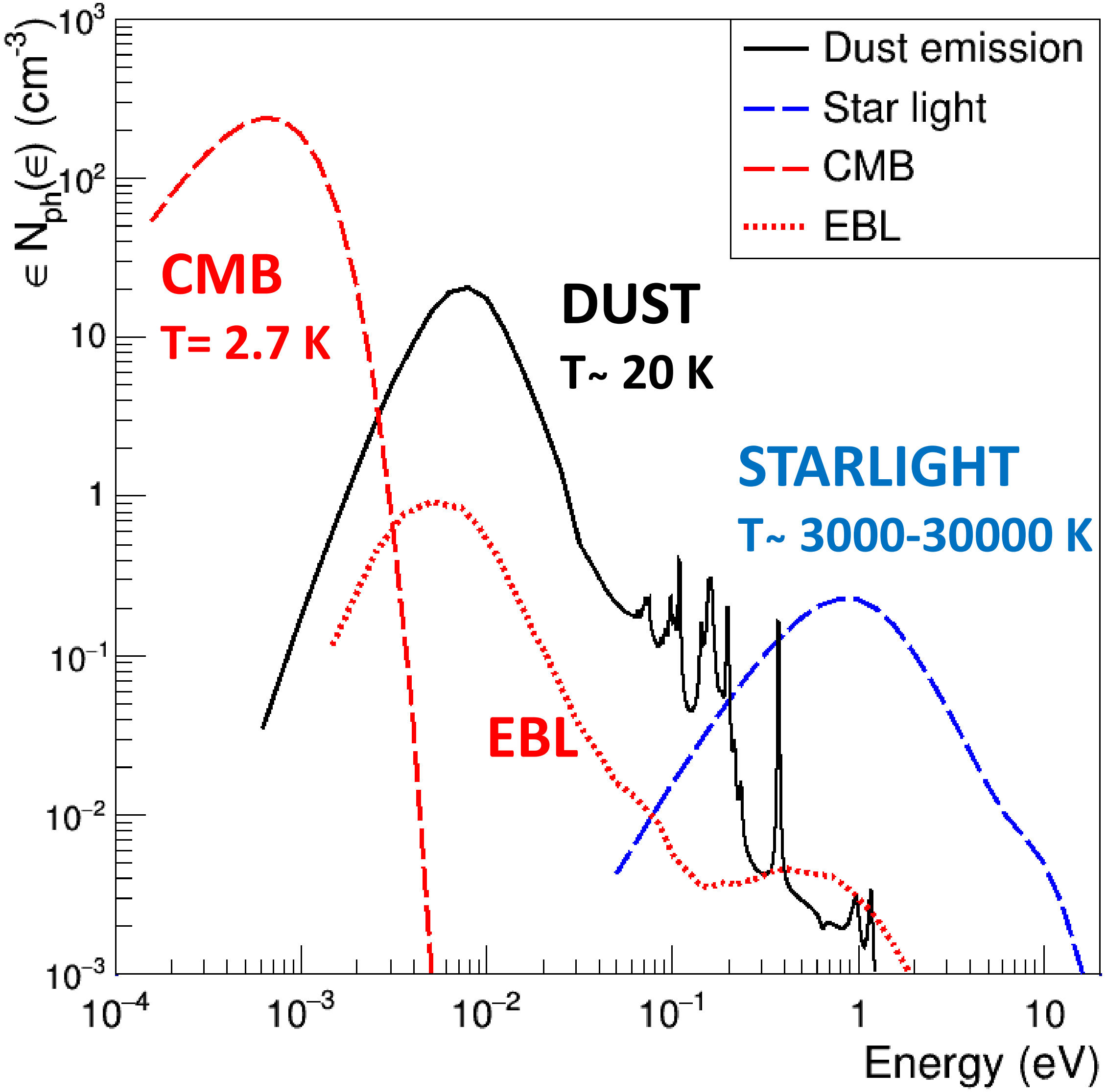
Maximum cross section for:

$$E_\gamma\,[TeV] = \frac{1.02}{\varepsilon\,[eV]}\frac{1}{(1 - cos\theta)}$$

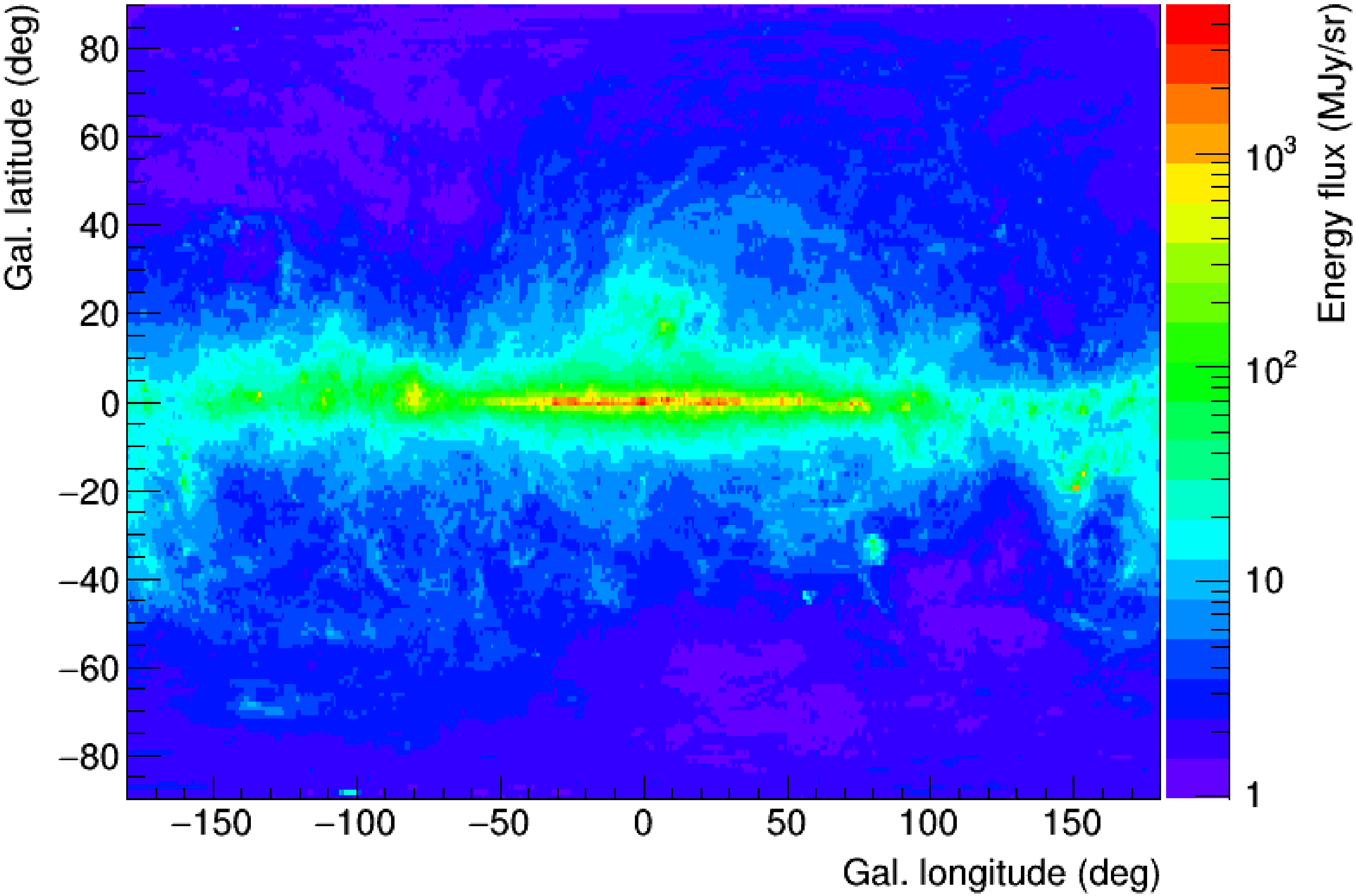
Flux attenuation:

$$F = F_0\, exp\,(-\tau\,(E_\gamma, \vec{x}))$$

Local radiation fields



IRAS/IRIS sky map at 100 μm



Model for infrared radiation at $\lambda > 40\ \mu m$

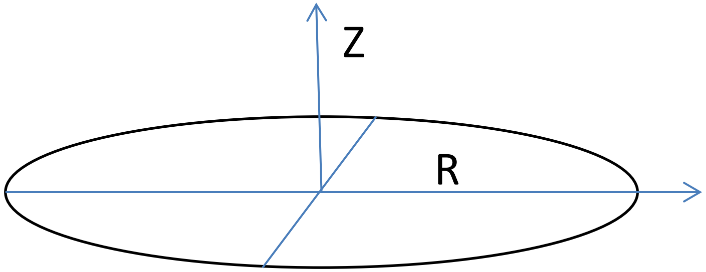
Dust emission model by *Misiriotis et al., A&A 417, 39, 2004* :

- "Cold" dust - heated by the diffuse star radiation (T ~ 19 - 14 K)
- "Warm" dust - heated locally by hot young stars (T = 35 K)
- Exponential distribution of the dust density in R and Z:

$$\rho\ (R, Z) = \rho(0,0)\ \ \exp(\frac{-R}{R_0} - \frac{Z}{Z_0})$$

- Blackbody emission & no absorbtion
- The model parameters are found fitting the COBE data

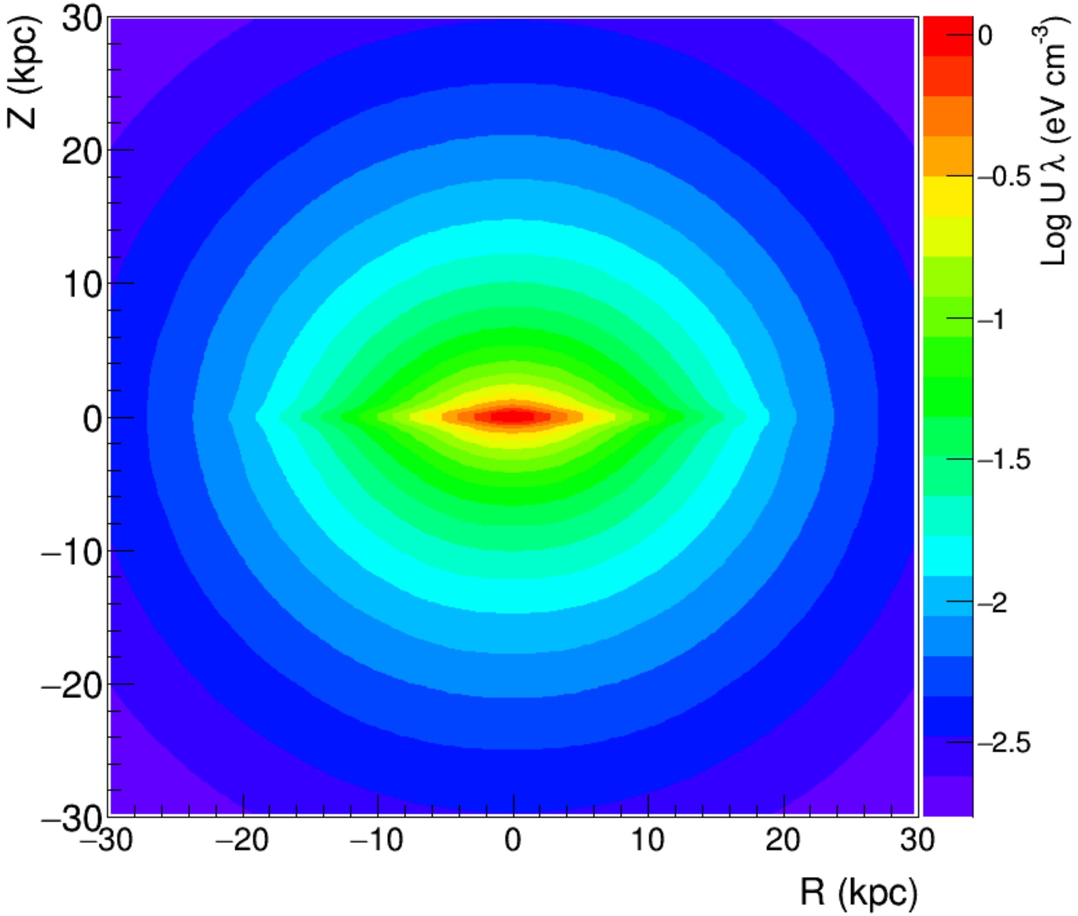
Cylindrical coordinates



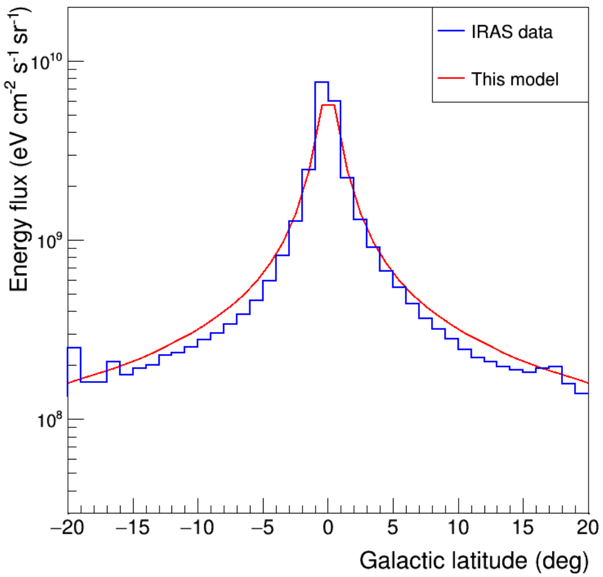
Integrating the dust emission over the Galaxy volume we calculated, for any position in the Galaxy disk and halo:

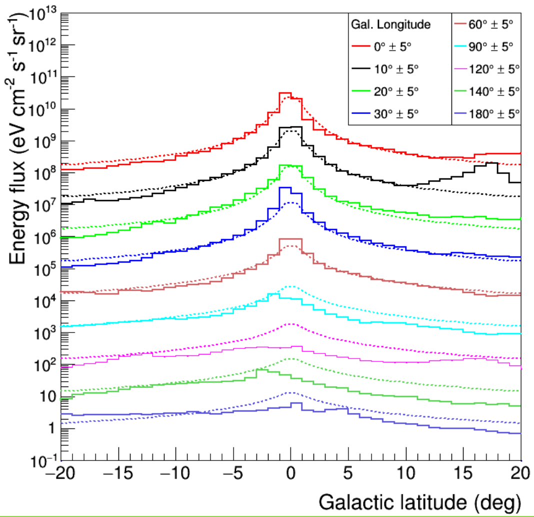
- infrared spectrum
- flux angular distribution

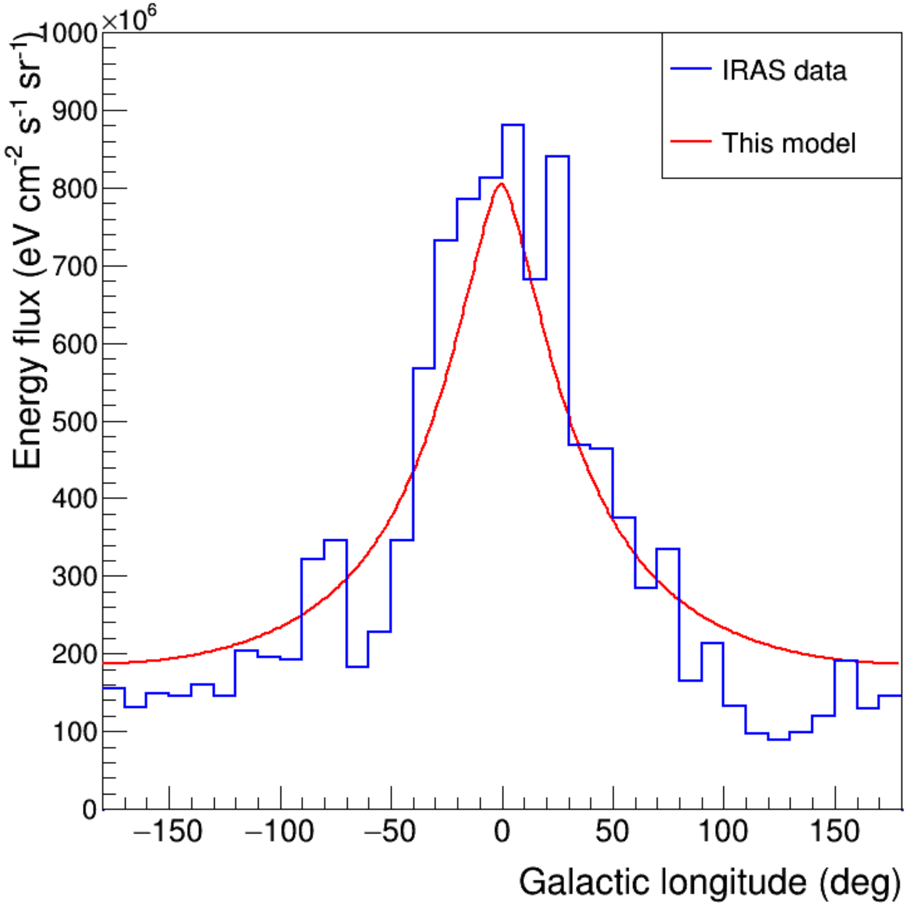
Energy density at 100 μm in the Milky Way



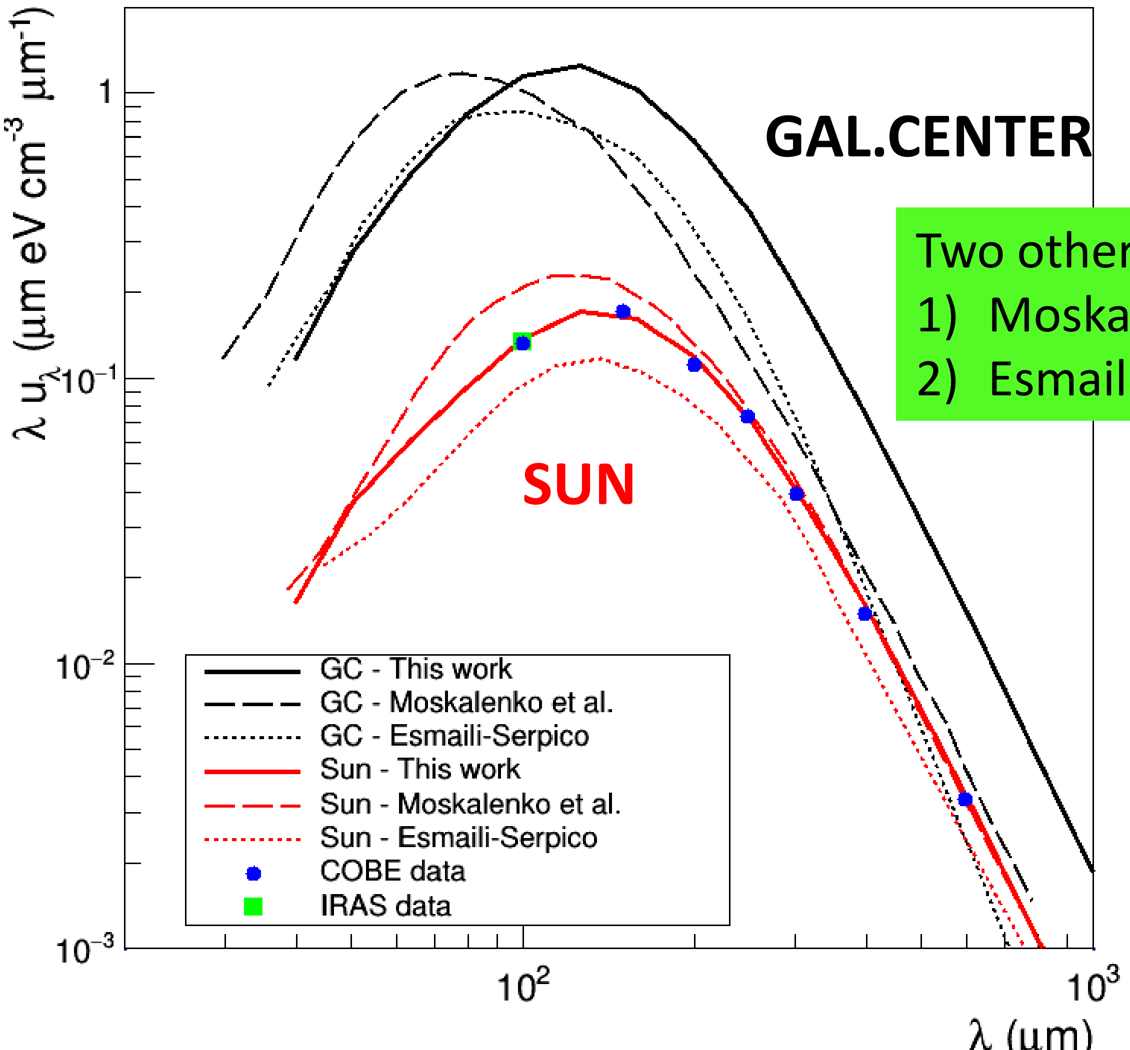
Model vs. data - 1
Latitude and longitude distributions at 100 μm





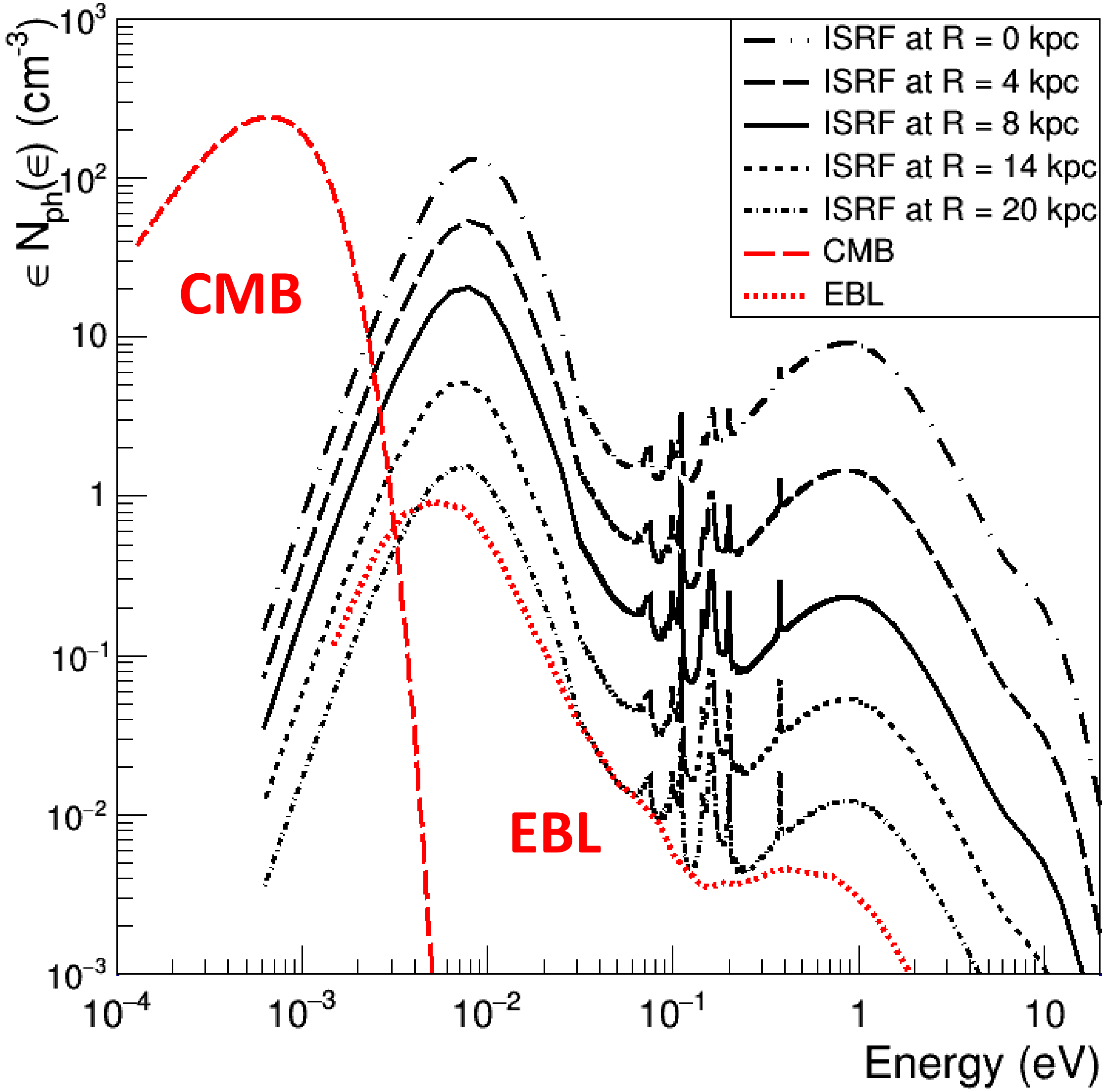


Model(s) vs. data - 2
Infrared spectrum



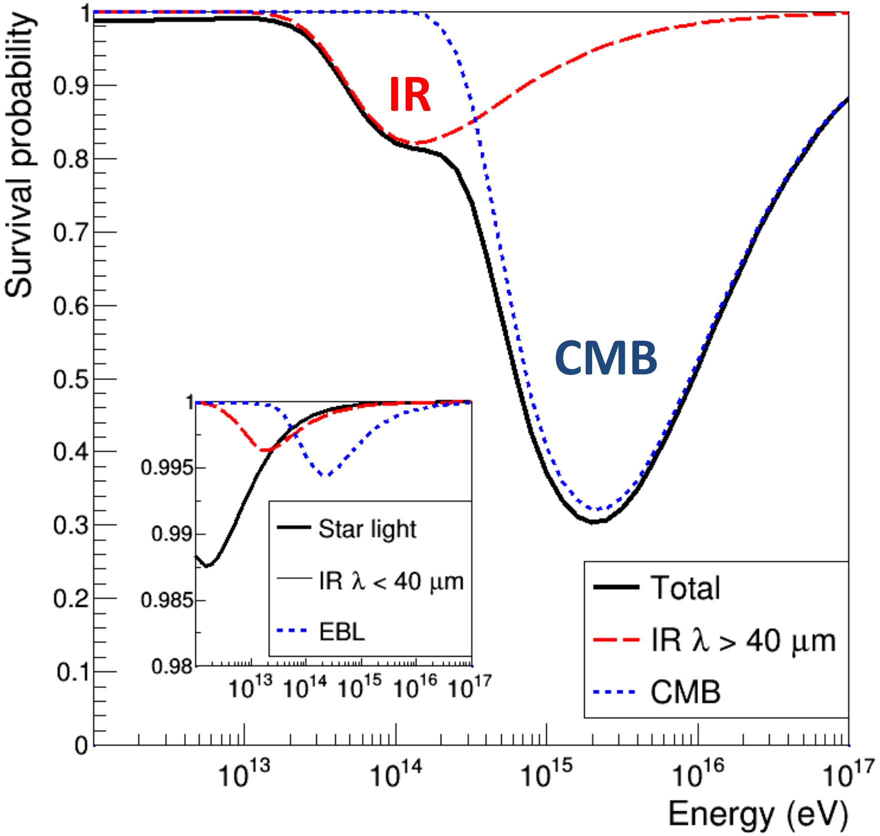
Two other models:
1) Moskalenko et al., 2006
2) Esmaili & Serpico, 2016

Radiation fields in the Galaxy

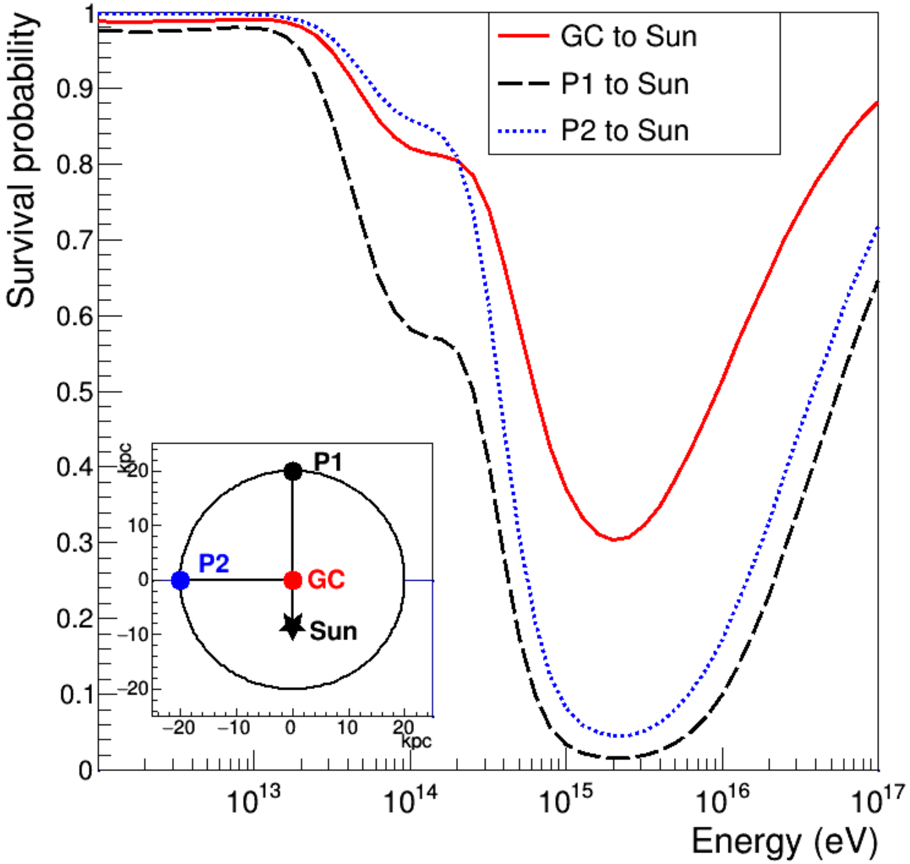


Survival probability vs. gamma ray energy

γ-rays from Galactic center



γ-rays from 3 source positions



Applications of the absorbtion model to galactic diffuse gamma ray fluxes

- Diffuse flux produced by cosmic ray interactions
  (emission from the galactic disk)

- Diffuse gamma rays associated to ICECUBE neutrinos
  - Dark matter model (by Esmaili & Serpico)
  - Halo model

  (spherical emission around the Galactic center)

Fermi LAT sky map E > 1 GeV

Galactic diffuse γ-rays are produced by cosmic ray (nuclei & electrons) interactions with the interstellar matter and radiation:

- π^0 decay
- Inverse Compton
- Bremsstrahlung

Most γ-rays come from the Galactic diffuse component

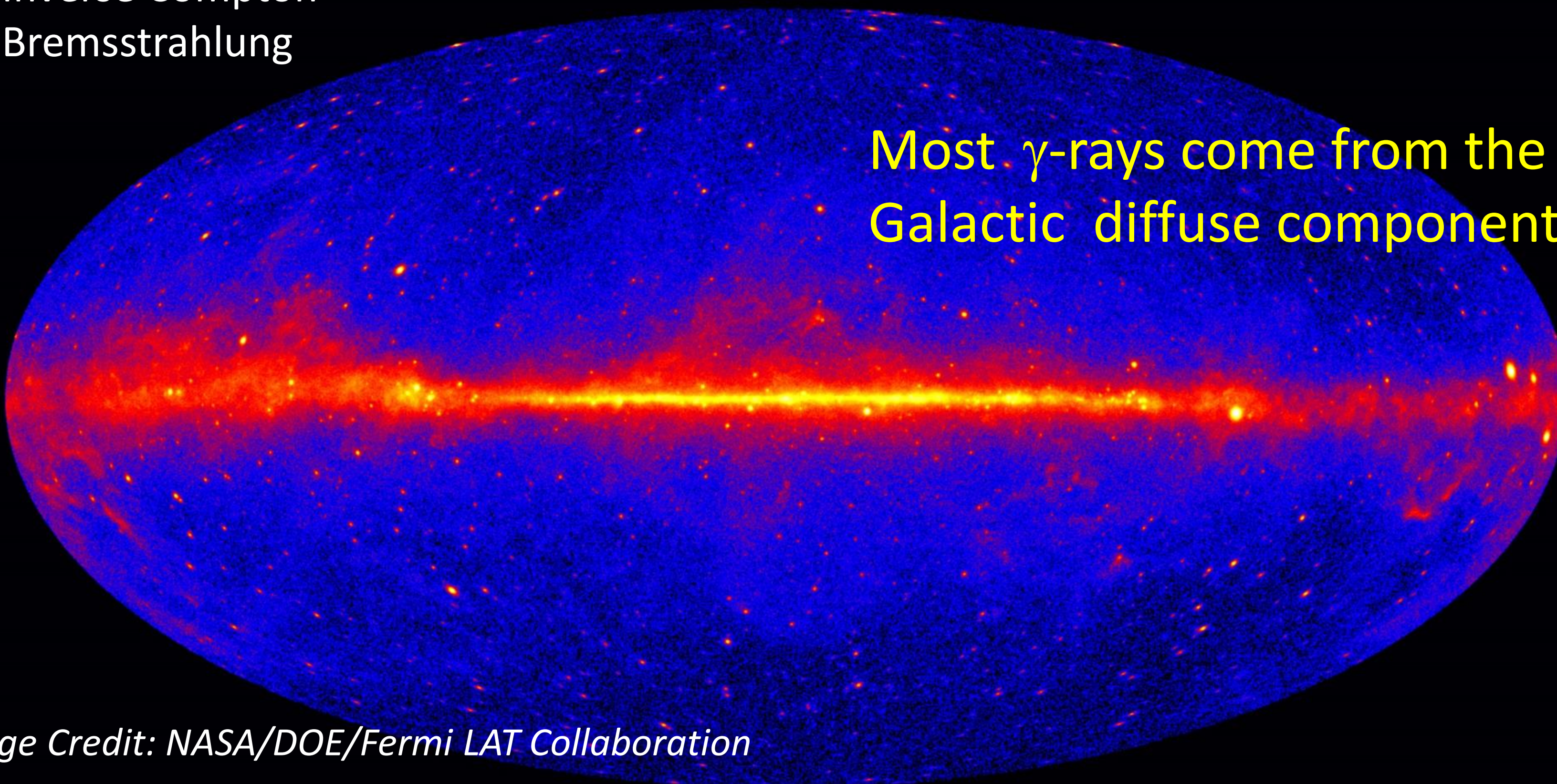


Image Credit: NASA/DOE/Fermi LAT Collaboration

Diffuse Galactic gamma ray flux data

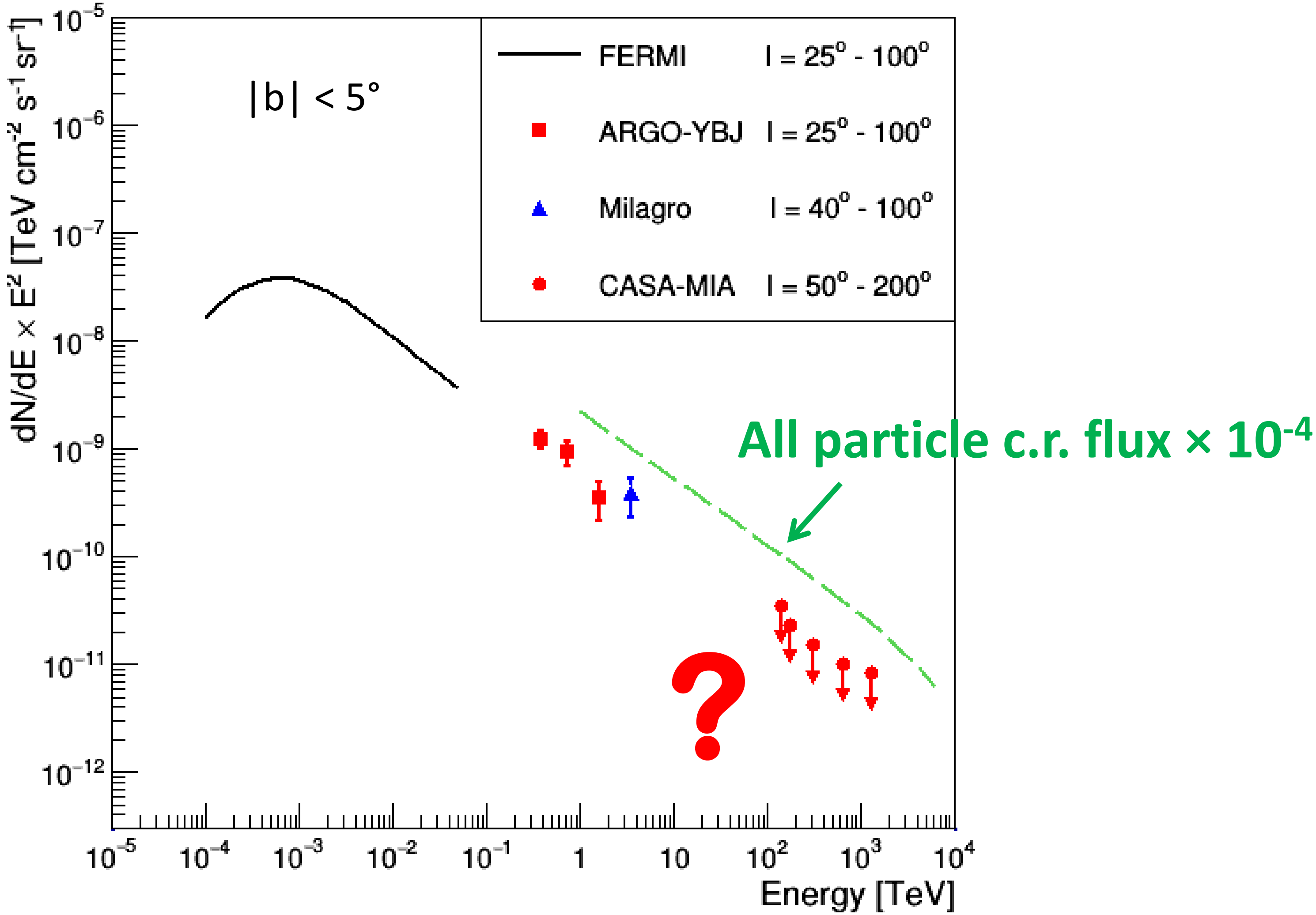
FERMI	100 MeV – 100 GeV	All sky		
HESS	E > 250 GeV	l = -75° to 60°	|b| < 2°	(2014)
ARGO-YBJ	0.3 - 1 TeV	l = 25° to 100°	|b| < 5°	(2015)
MILAGRO	> 3.5 TeV	l = 40° to 100°	|b| < 5°	(2005)
	15 TeV	l = 30° to 85°	|b| <10°	(2008)

Above 100 TeV only upper limits: BASJE, EASTOP, UMC…

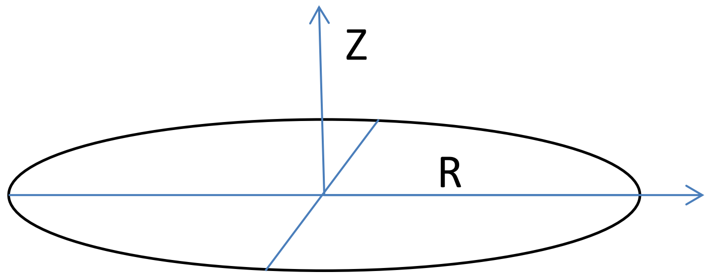
The lowest are:

CASA-MIA	140-1300 TeV	l = 50° to 200°	|b| < 2°,5°,10°	(1996)

Galactic diffuse gamma ray flux



Two simple phenomenological models to describe the Galactic diffuse gamma ray emission



Spatial distributions:

Exponential model:

$$q_\gamma (R,Z) = C \ \exp\left(\frac{-R}{R_0} - \frac{|Z|}{Z_0}\right)$$

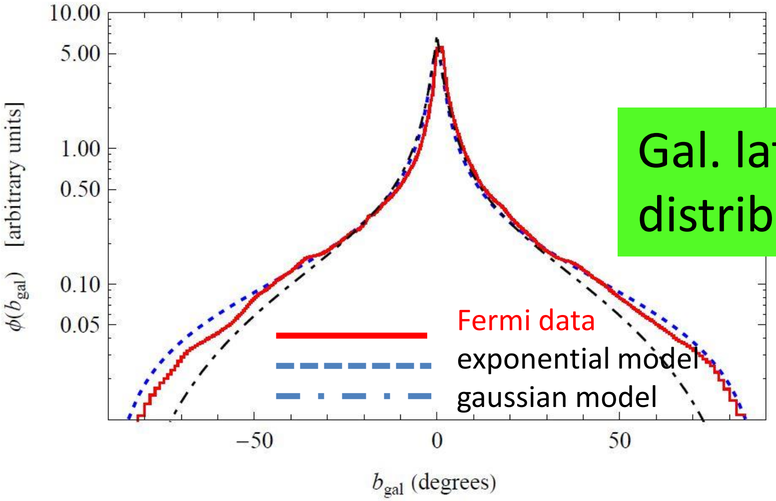
R_0 = 3.9 kpc Z_0 = 0.27 kpc

Gaussian model:

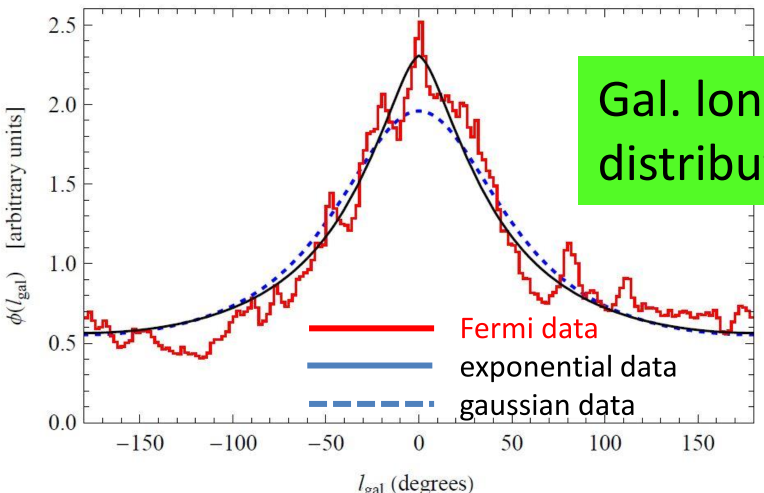
$$q_\gamma (R,Z) = C' \ \exp\left(\frac{-R^2}{2R^2{}_0} - \frac{|Z|2}{2Z^2{}_0}\right)$$

R_0 = 5.2 kpc Z_0 = 0.22 kpc

γ-ray flux (10-100 GeV)

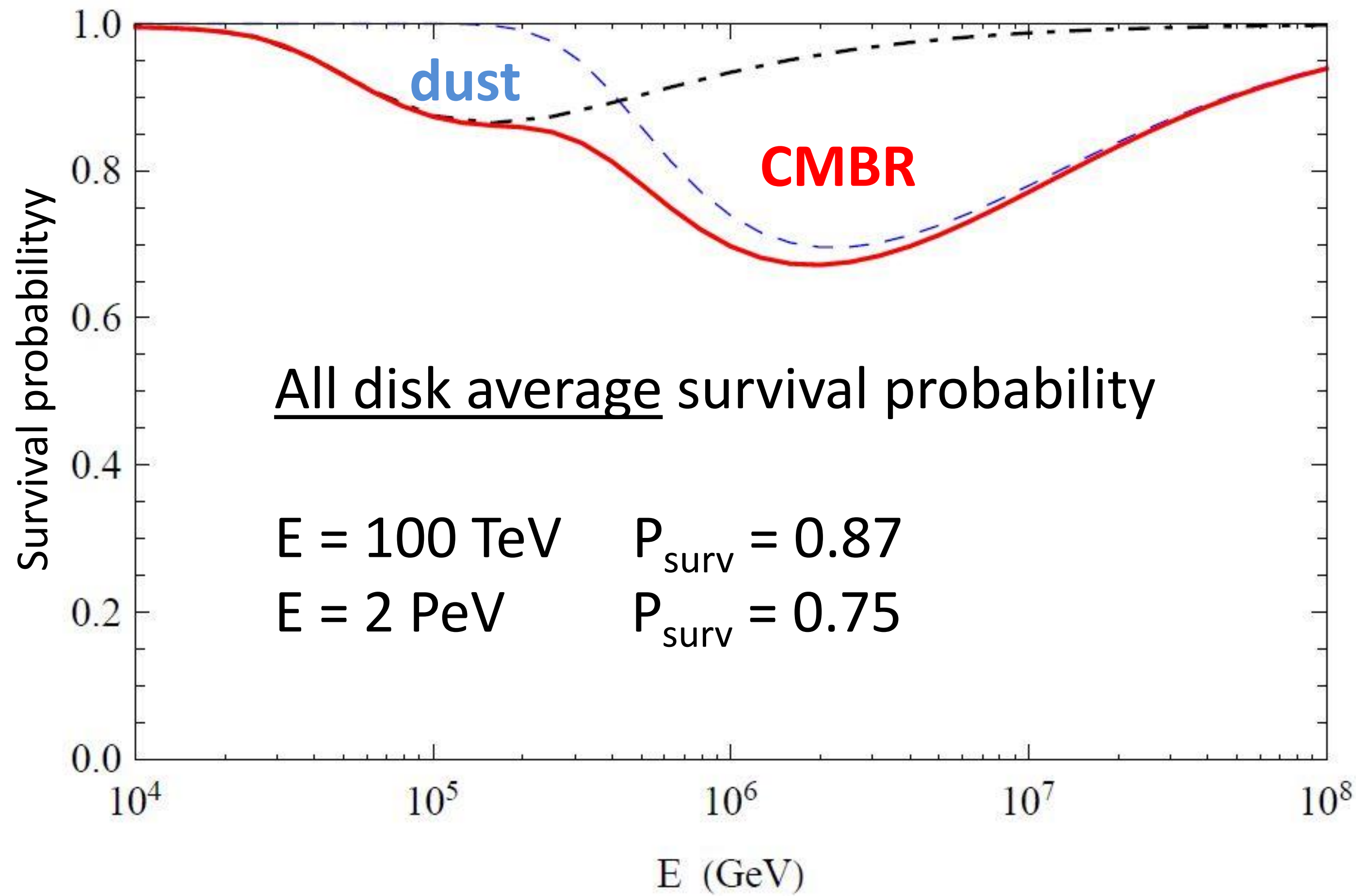


Gal. latitude distribution

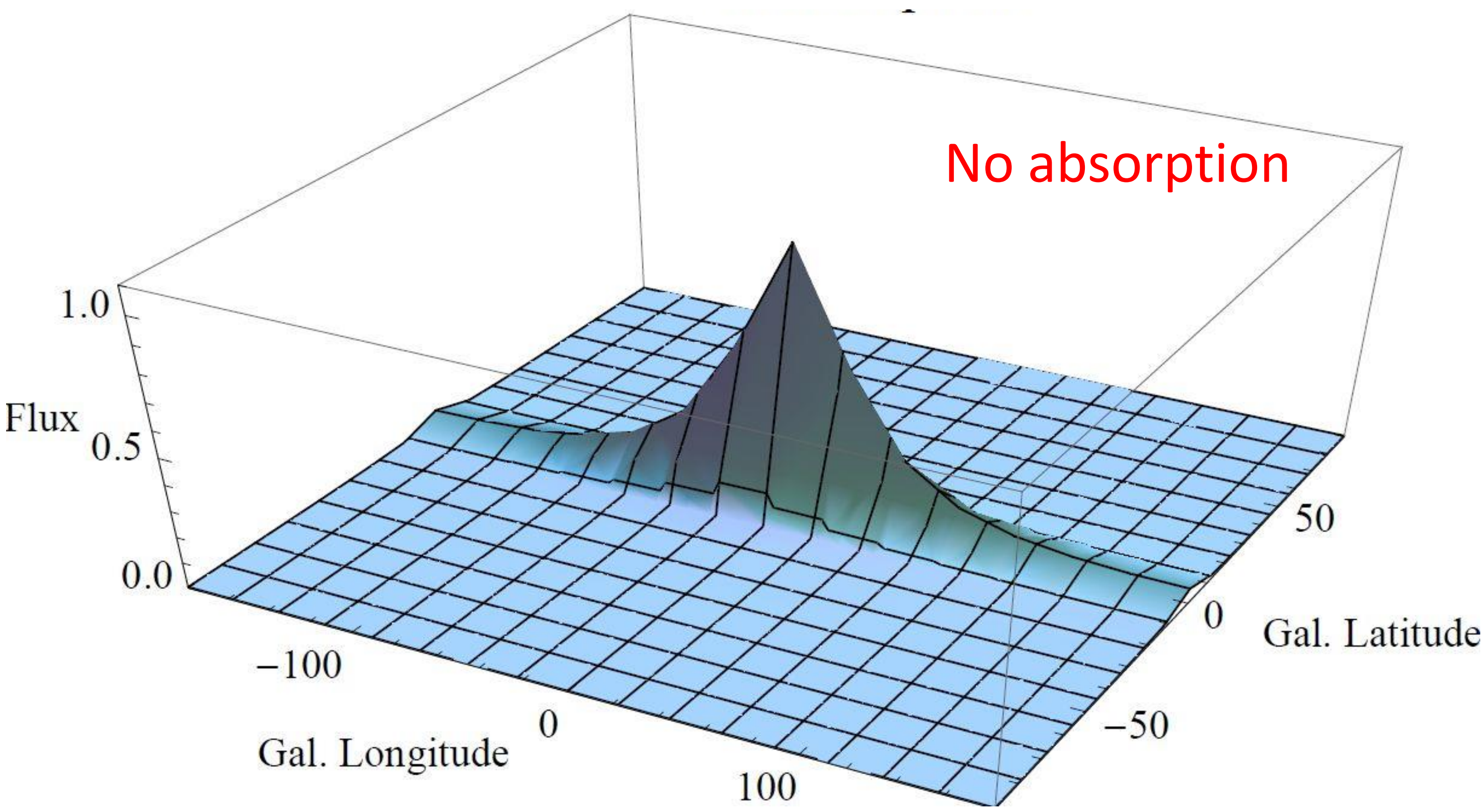


Gal. longitude distribution

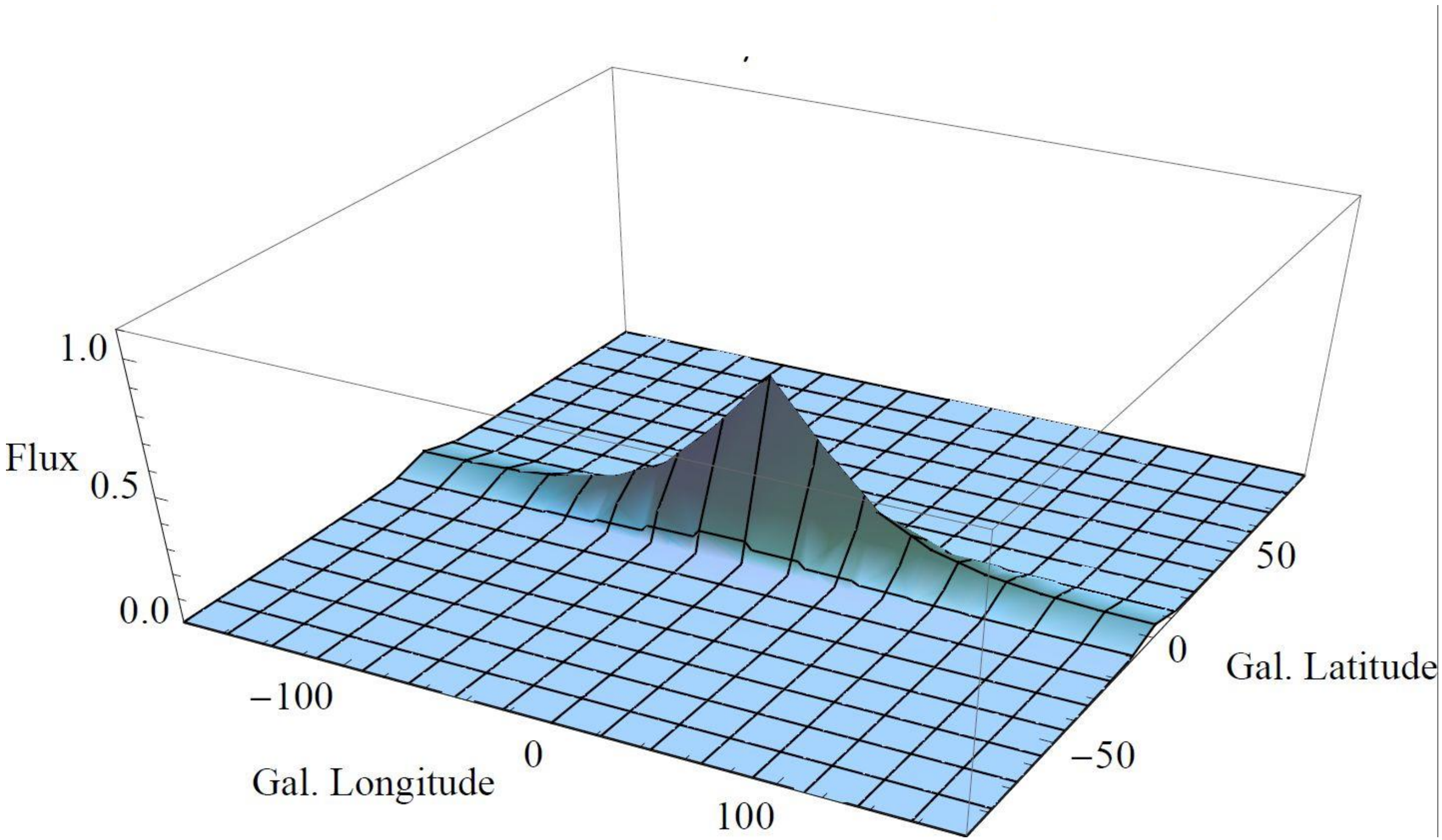
Galactic diffuse gamma-ray absorption for the disk exponential model



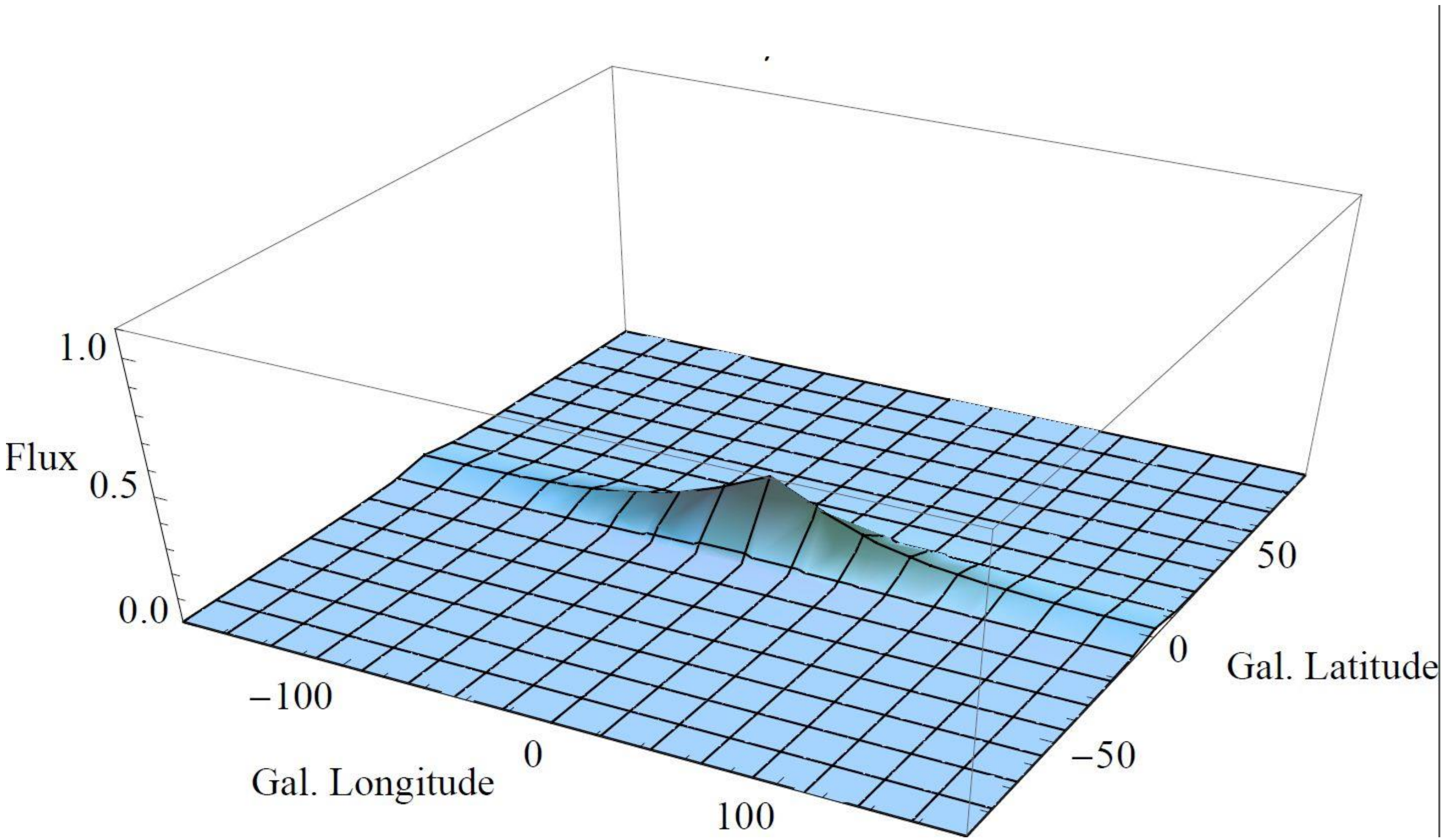
Galactic diffuse gamma ray flux



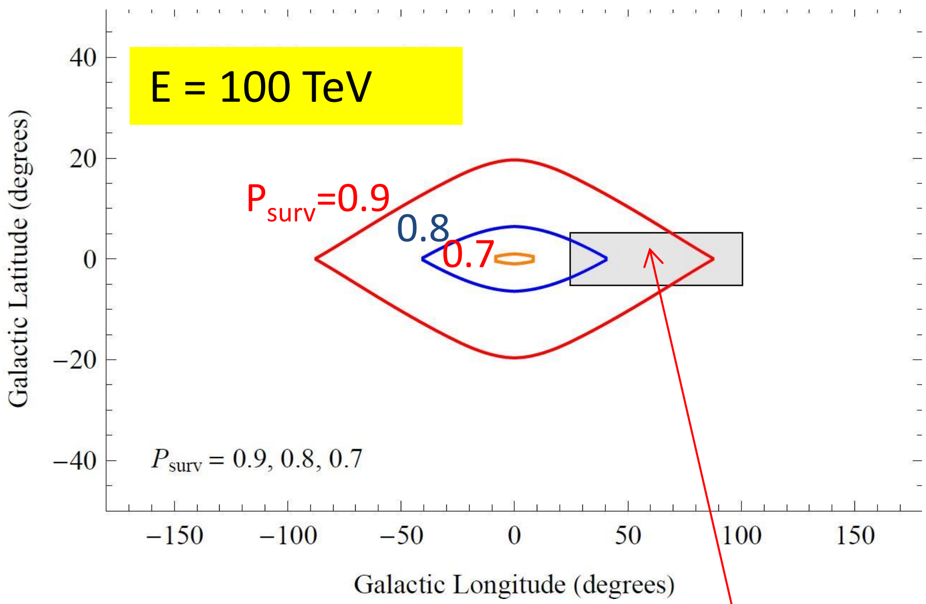
Surviving flux at 100 TeV

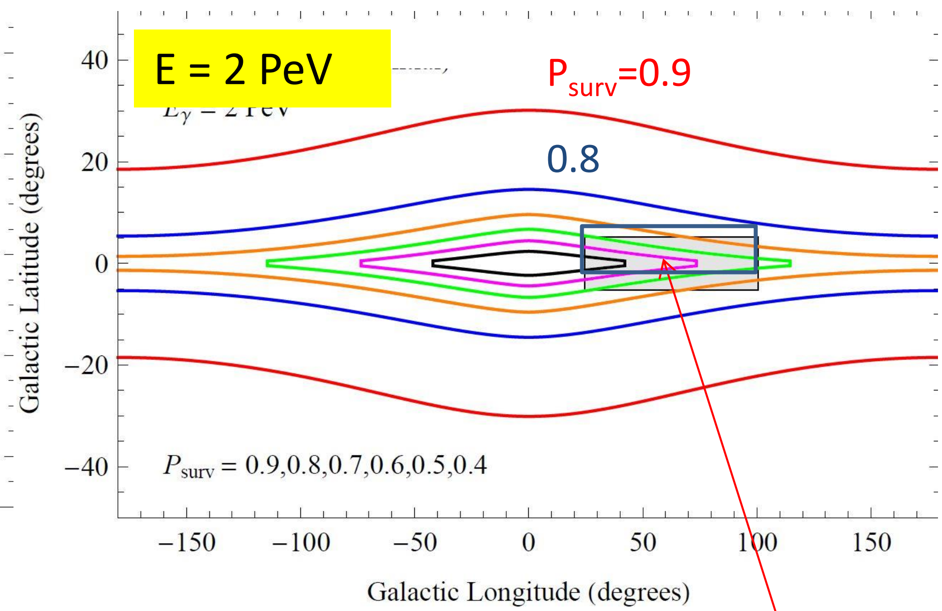


Surviving flux at 2 PeV



Survival probability of the Galactic diffuse flux

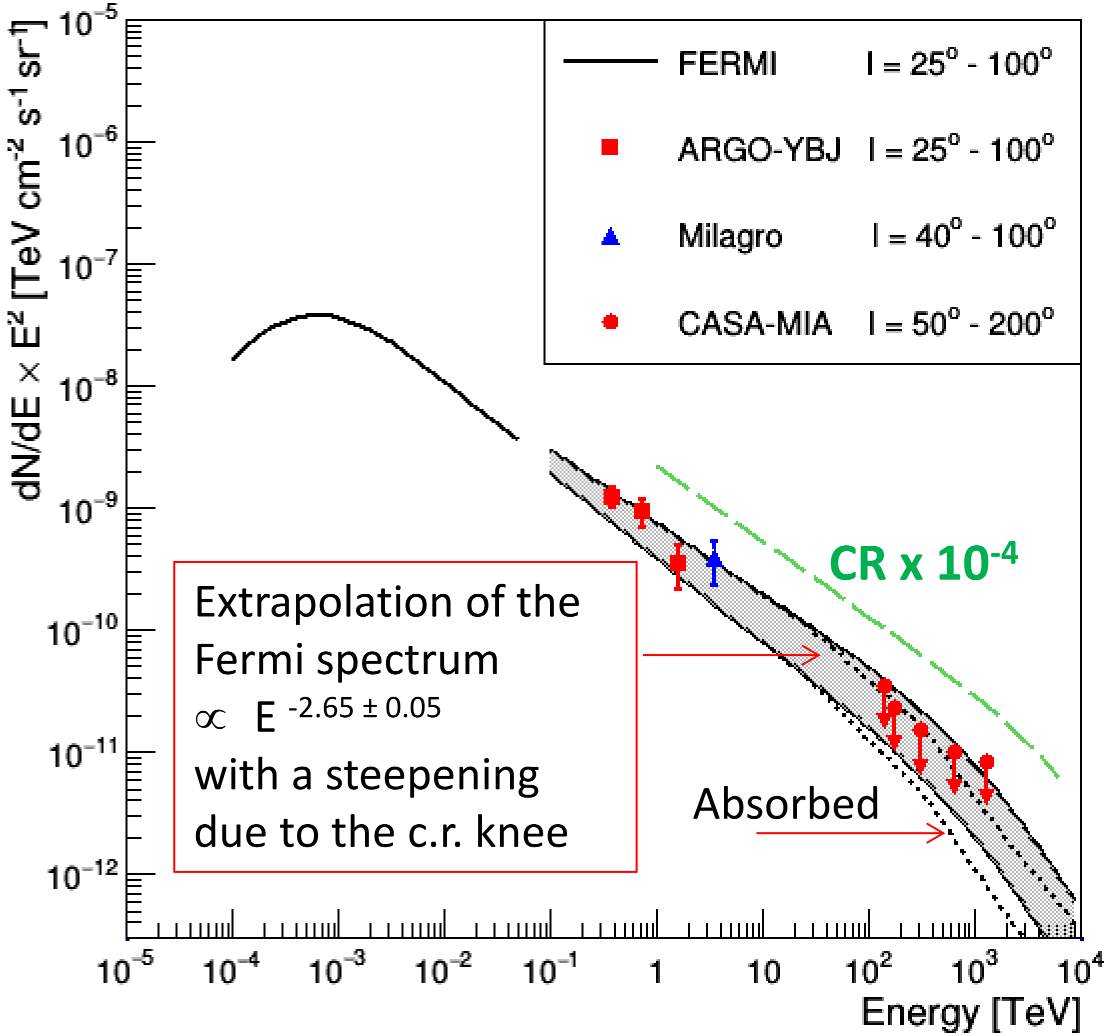




Region l=25°-100° |b|= 5°
P_{surv} = 0.75

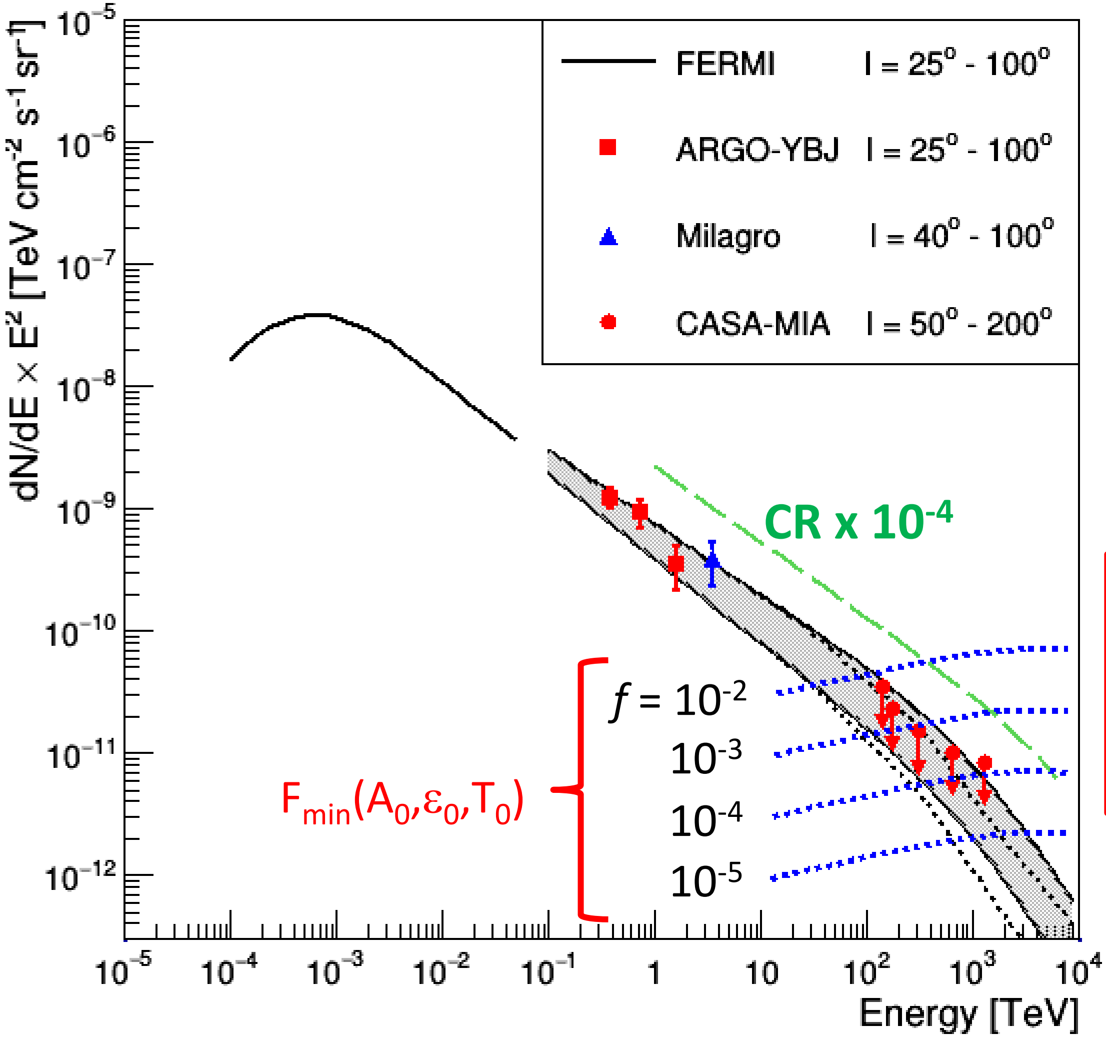
Region l=25°-100° |b|= 5°
P_{surv} = 0.51

Galactic diffuse gamma ray flux



Extrapolation of the Fermi spectrum $\propto E^{-2.65 \pm 0.05}$ with a steepening due to the c.r. knee

Detector sensitivity to the diffuse gamma ray flux in the disk region l = 25° -100° and |b| < 5°



Detector features:

- Effective area $A_0 = 1$ km^2
- γ-ray detection efficiency $\varepsilon_0 = 1$
- Observation time $T_0 = 1$ year
- Latitude 30° N
- Maximum zenith angle 45°

Minimum observable flux (5 σ)

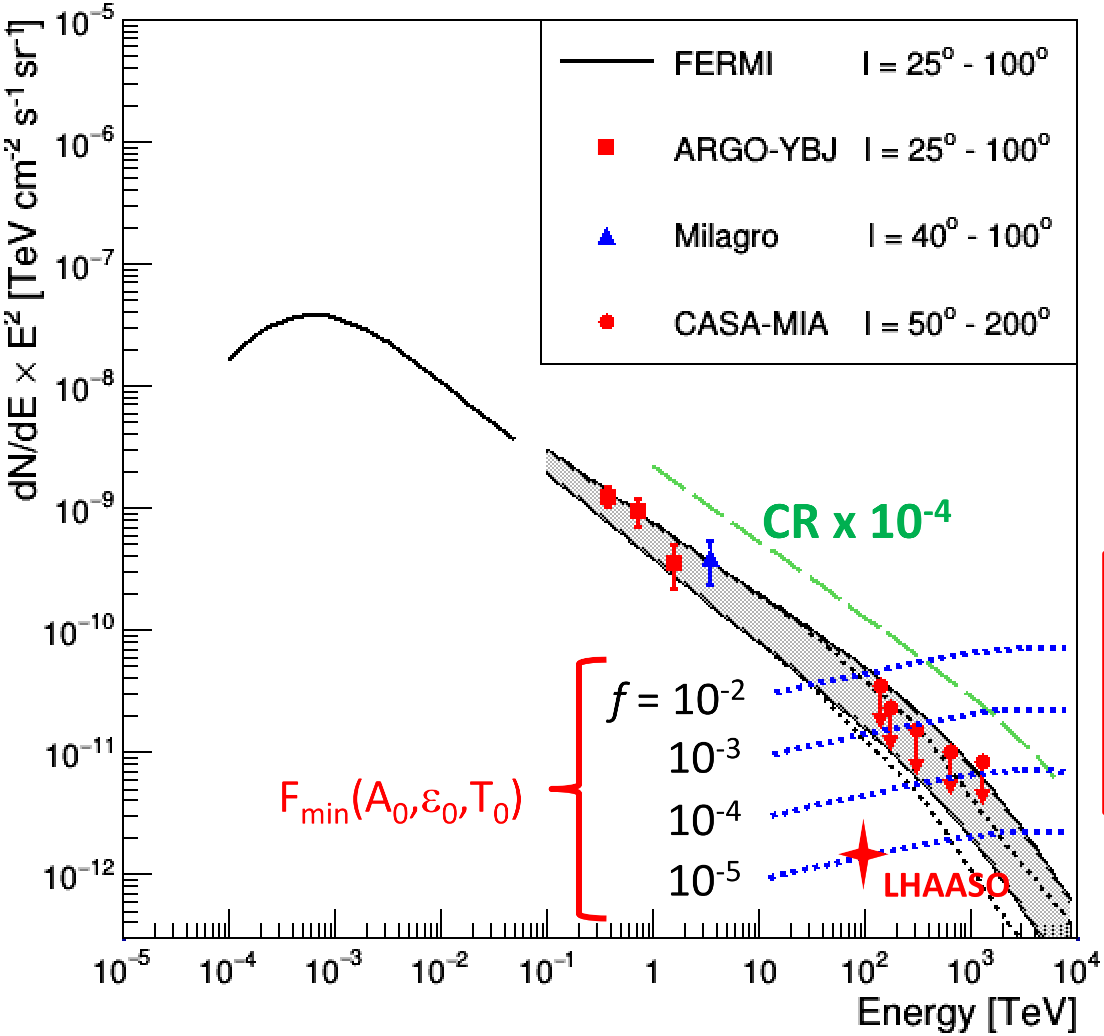
$F_{min}(A_0,\varepsilon_0,T_0)$ for different values of f

f = background rejection factor

Minimum flux for any A, ε and T:

$$F_{min}(A,\varepsilon,T) = F_{min}(A_0,\varepsilon_0,T_0)\sqrt{\frac{A_0 T_0}{AT}\frac{\varepsilon_0}{\varepsilon}}$$

Detector sensitivity to the diffuse gamma ray flux in the disk region l = 25° -100° and |b| < 5°



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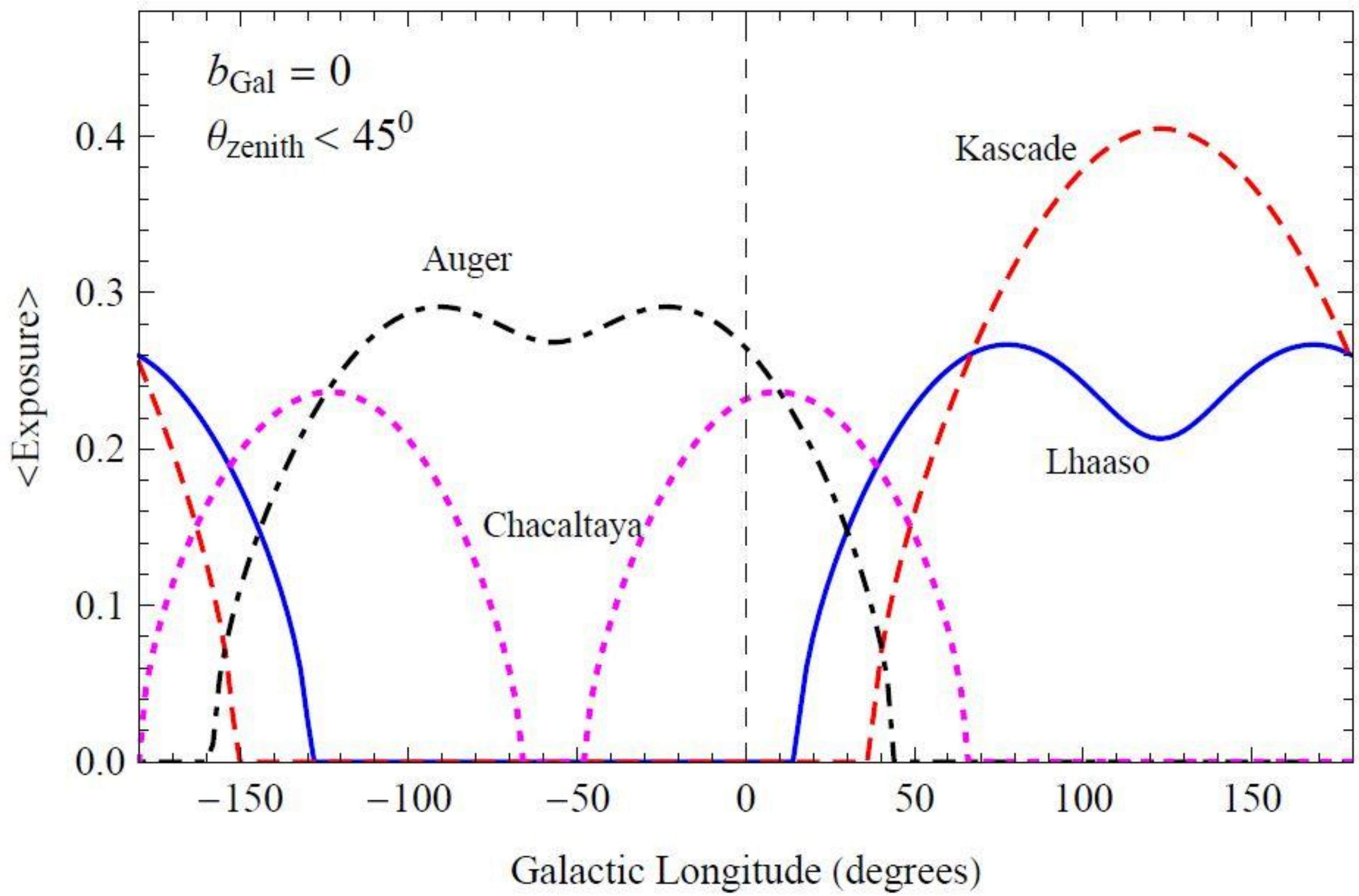
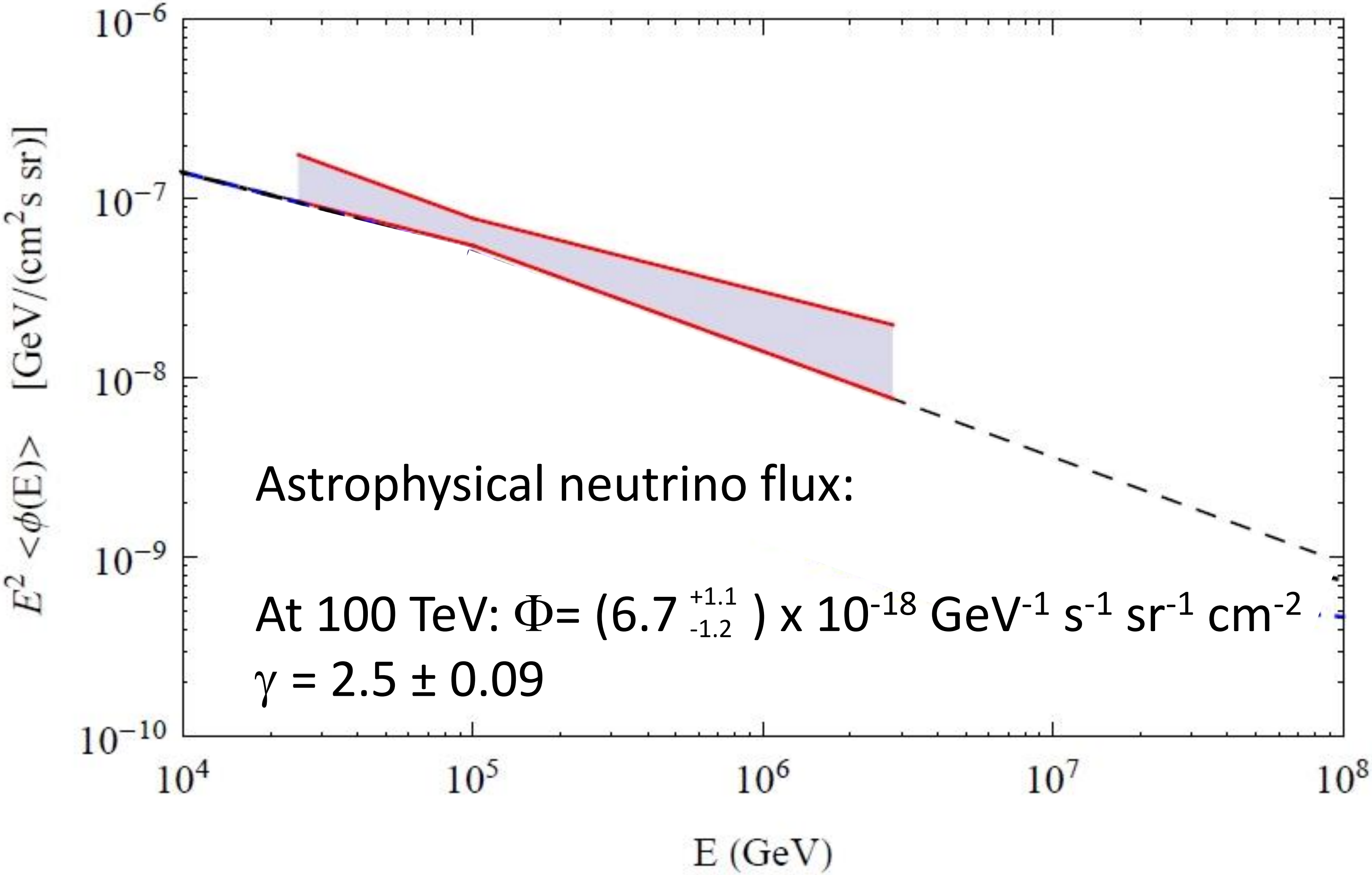
Detectors exposure for the Galactic Plane



ICECUBE neutrinos



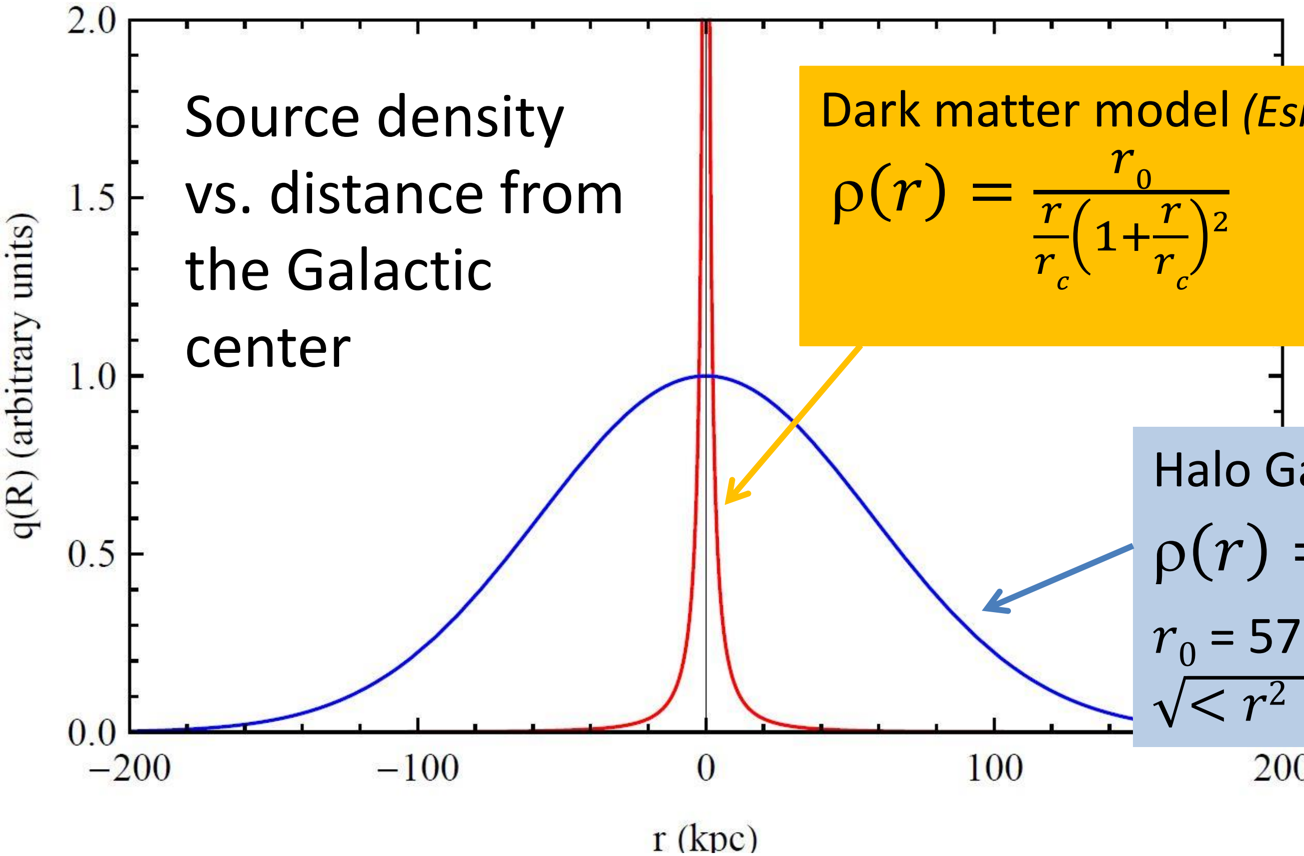
Astrophysical neutrino flux:

At 100 TeV: $\Phi = (6.7\,^{+1.1}_{-1.2}) \times 10^{-18}$ GeV^{-1} s^{-1} sr^{-1} cm^{-2}

$\gamma = 2.5 \pm 0.09$

Gamma rays associated to ICECUBE neutrinos ?

Two models with a spherical spatial distributions of sources around the Galactic center



Source density vs. distance from the Galactic center

Dark matter model *(Esmaili & Serpico, 2015)*

$$\rho(r) = \frac{r_0}{\frac{r}{r_c}\left(1+\frac{r}{r_c}\right)^2}$$

r_c = 20 kpc

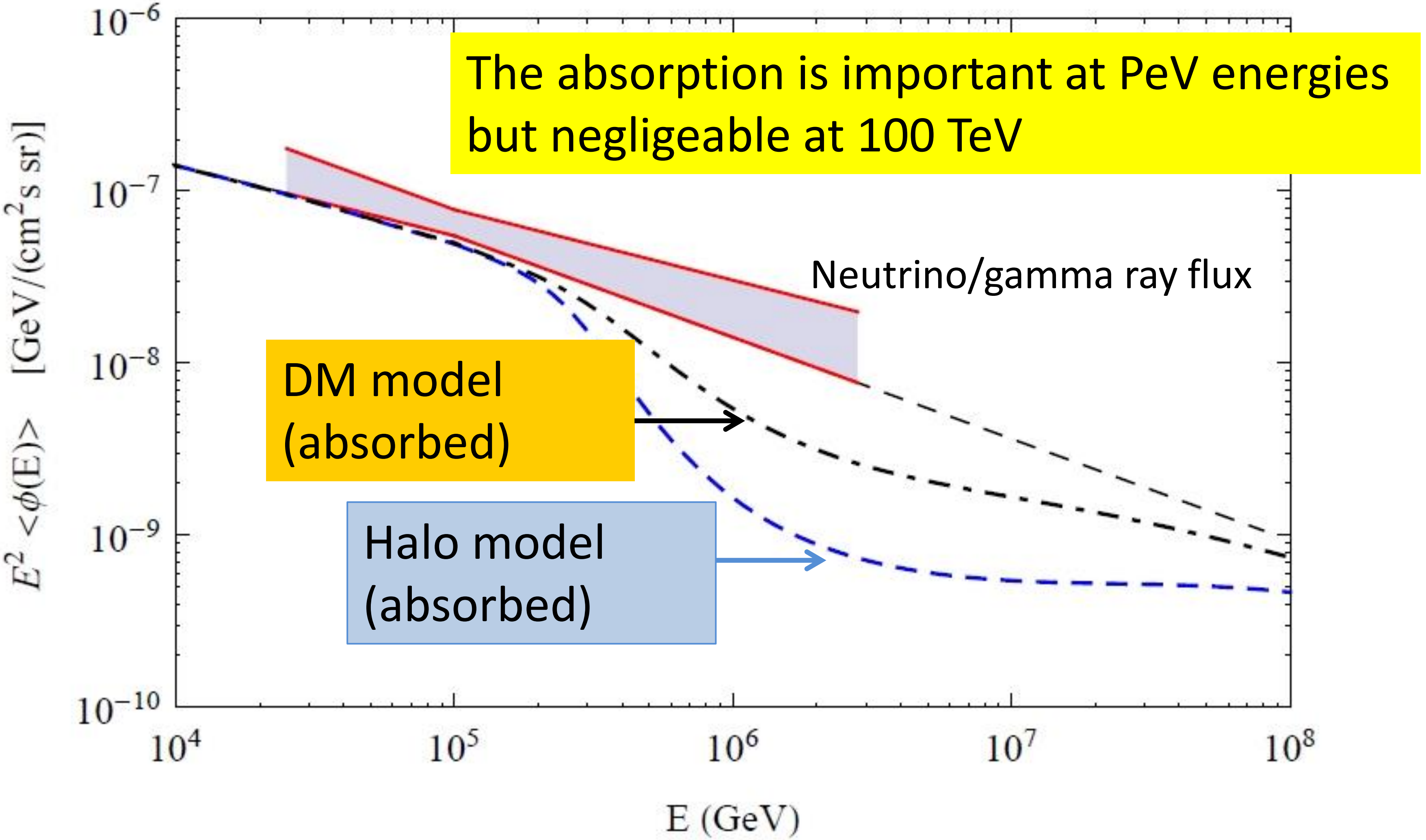
Halo Gaussian model:

$$\rho(r) = \exp\left(\frac{-r^2}{2r_0^2}\right)$$

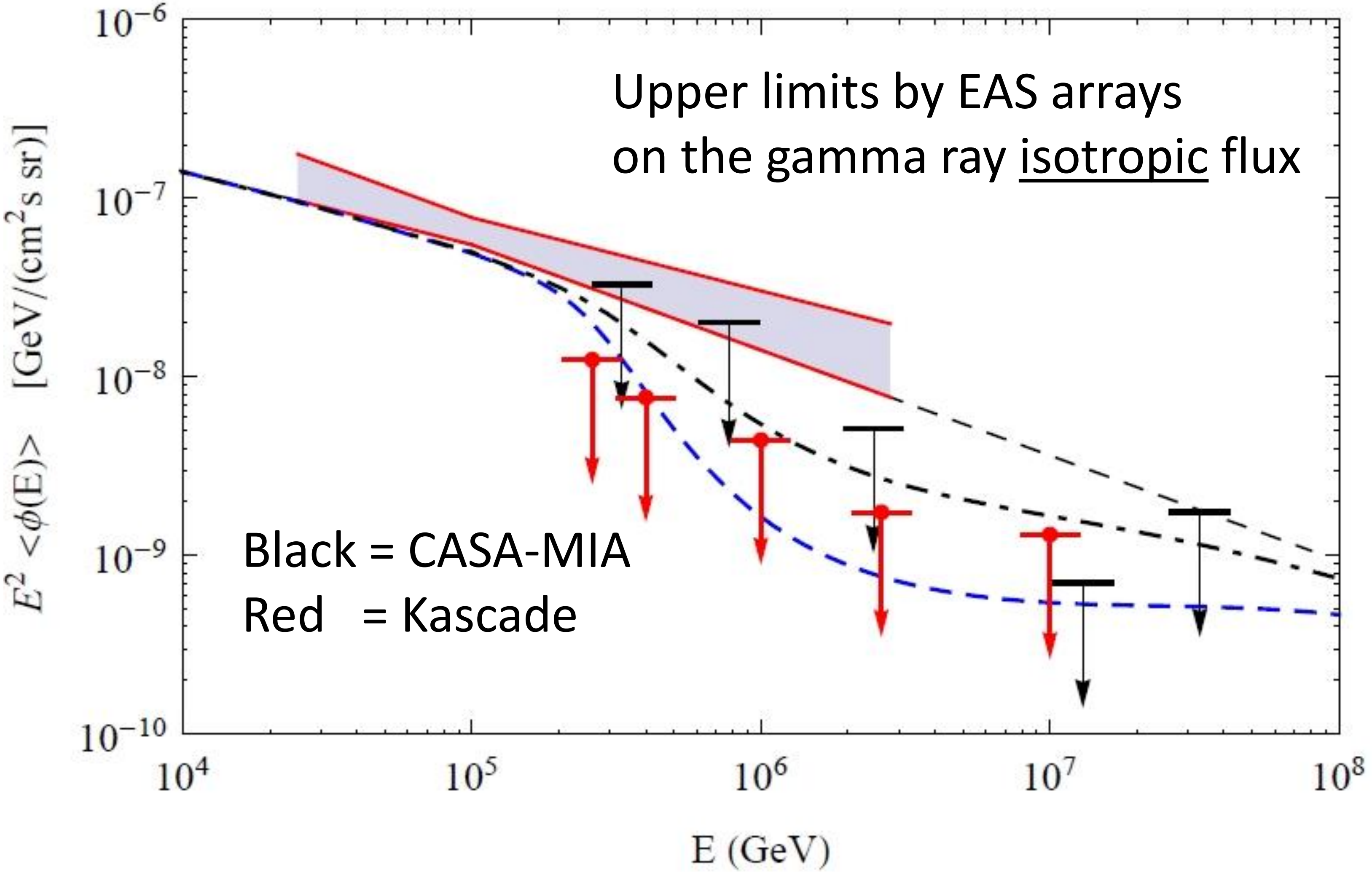
r_0 = 57 kpc

$\sqrt{< r^2 >}$ = 100 kpc

Gamma ray absorption for DM and halo models



DM and halo models vs. data



Conclusions

- The gamma ray sky at energies ≥100 TeV will be explored for the first time by a new generation of high sensitivity gamma ray detectors.

- The measurement of the spectra of individual objects will be crucial to determine the emission mechanism of the sources.

- The study of diffuse fluxes with wide fields of view instruments will be also of great importance for the understanding of High Energy processes in the Galaxy.

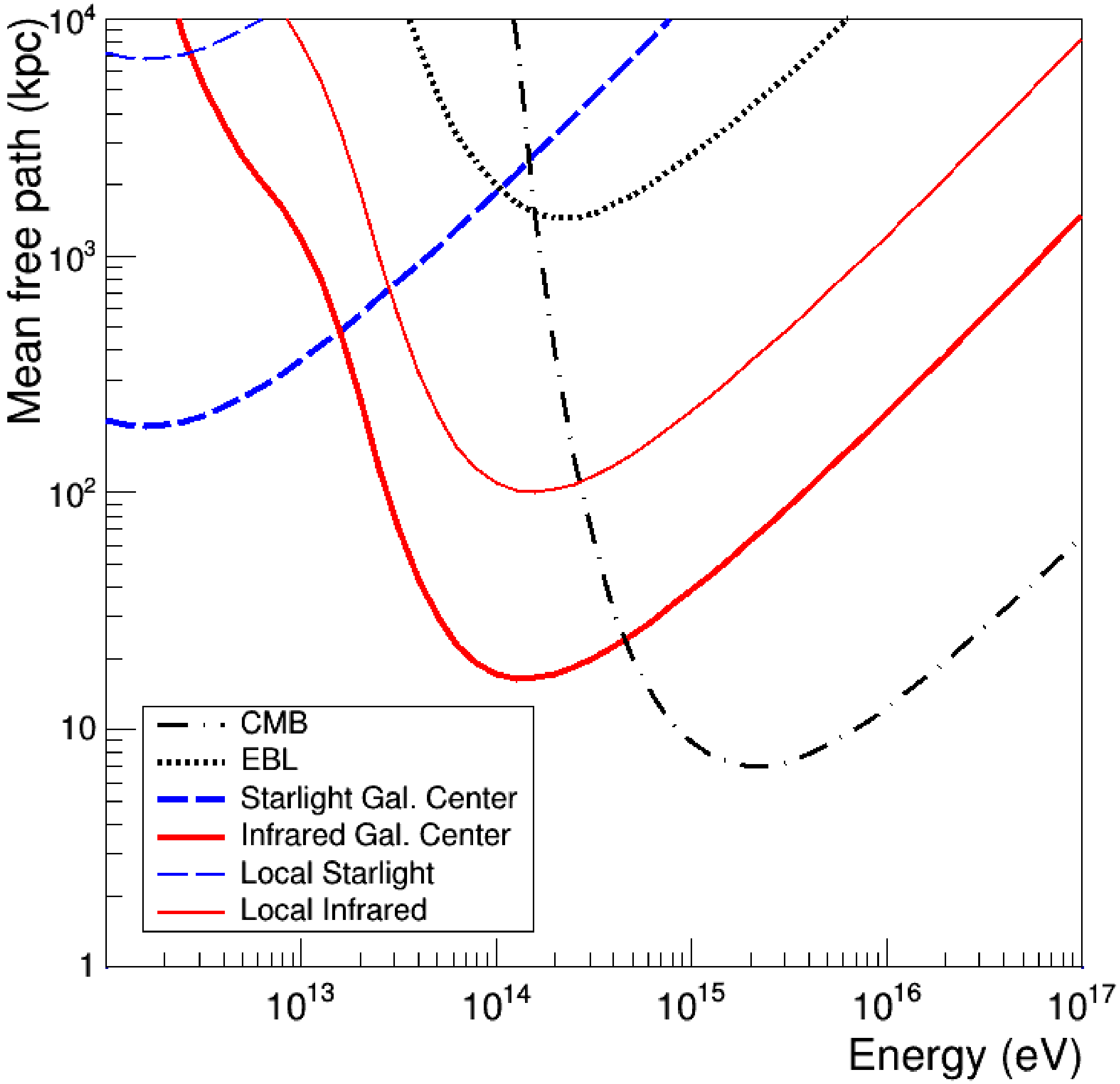
- Gamma Ray absorption in the Galactic radiation fields must be carefully considered, but does not preclude the study.

- Telescopes with an effective area of 1 km^2 and good rejection capabilities should be able to measure the diffuse gamma ray flux generated by cosmic rays interactions in the disk of the Galaxy in most models for this emission.

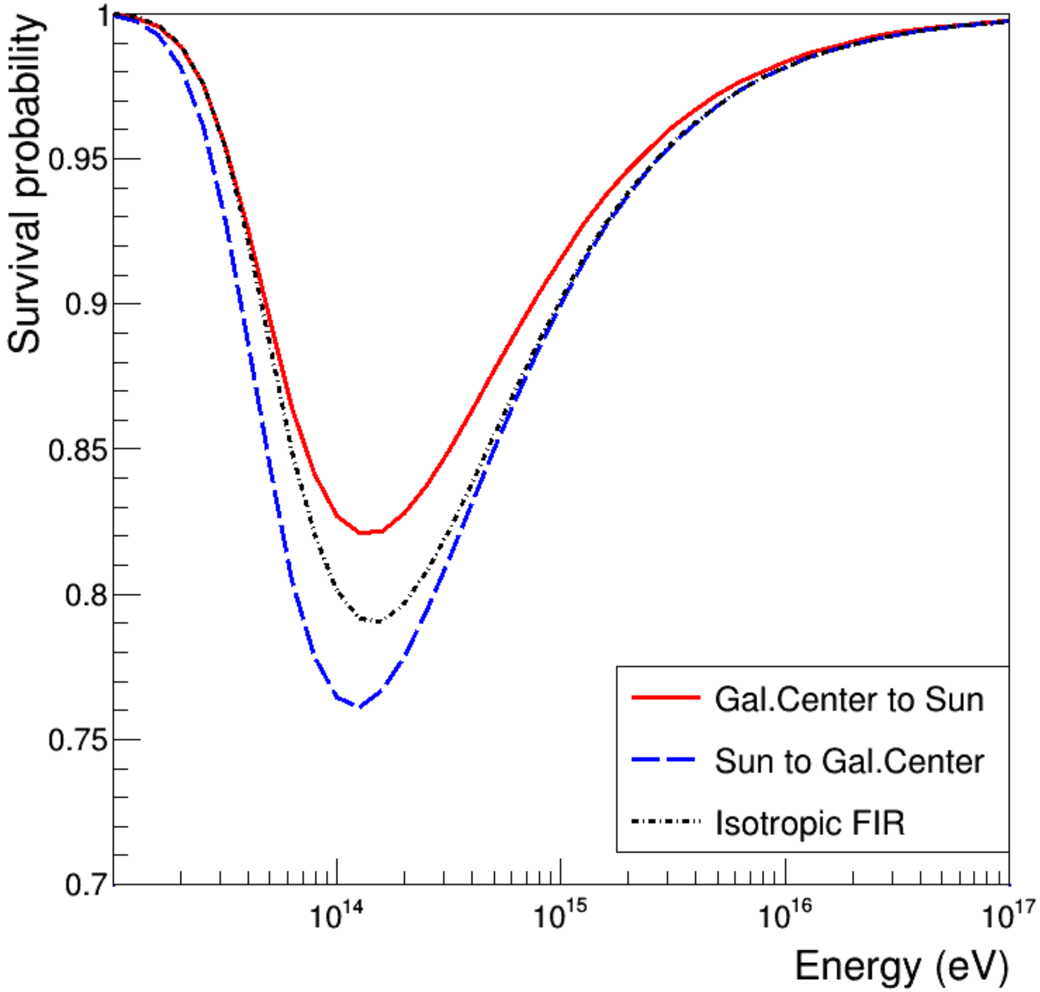
- If the ICECUBE astrophysical neutrinos have a significant galactic component, the associated gamma ray emission should be detectable by the new telescopes.

Backup slides

Mean free path

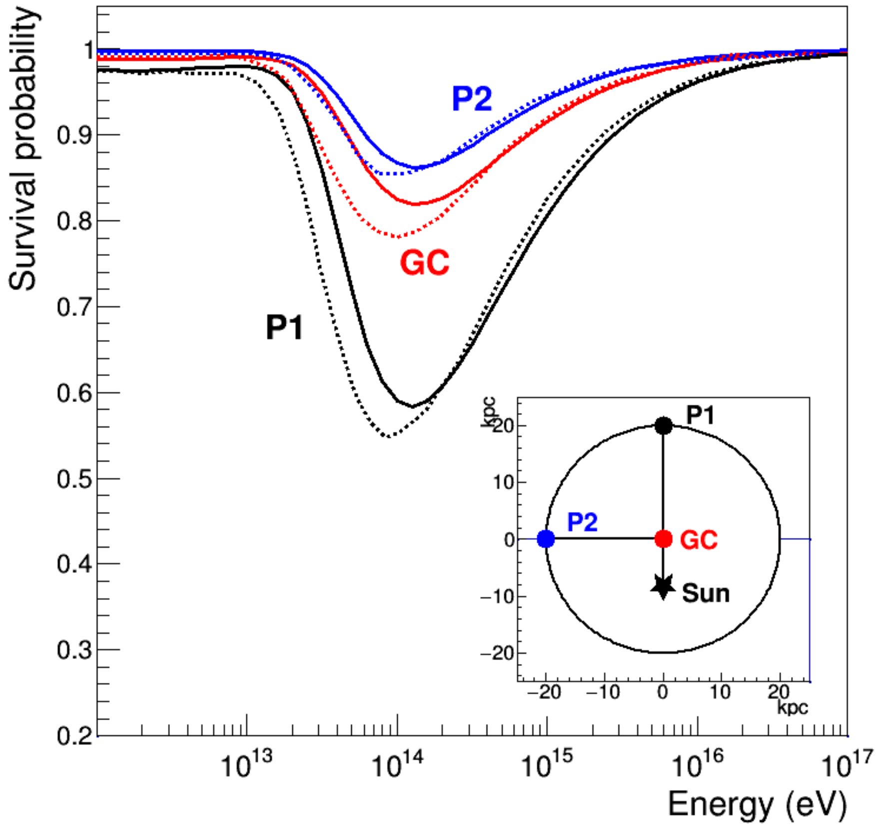


Infrared radiation anisotropy



Survival probability: models comparison

Solid lines: our model
Dotted lines: Moskalenko et al.



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