Propagation of Gamma Rays in the Galaxy

S.Vernetto

INAF-OATO, INFN Torino, Italy

7th Workshop

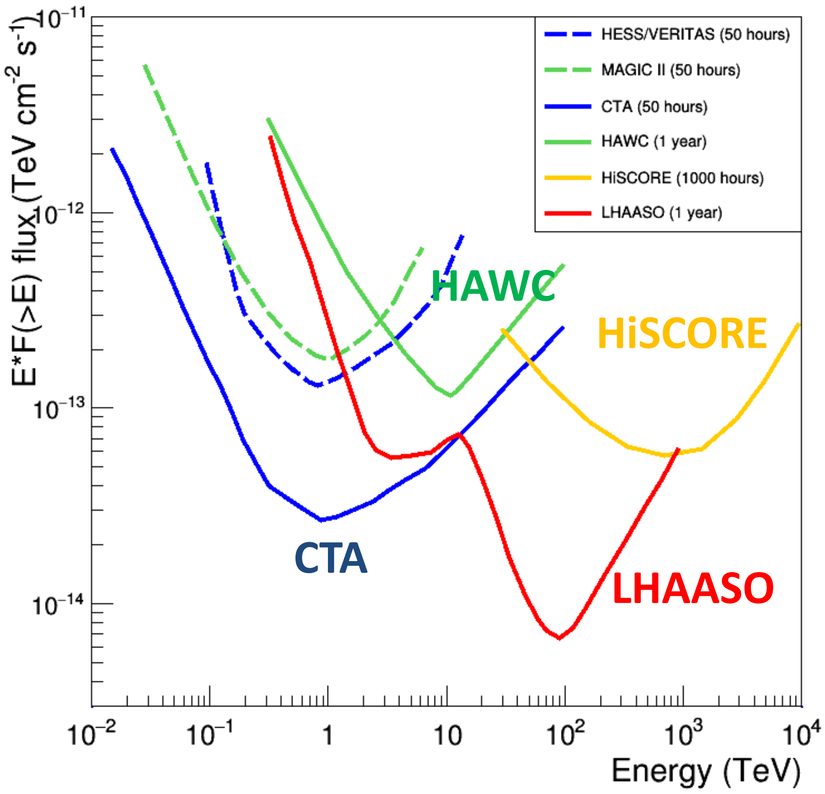
on Air Shower Detection at High Altitude

2016 Nov 30 - Dec 2, Torino

Zodiacal light by L.Argerich

Gamma ray astronomy at E > 30 TeV

Integral point source sensitivity



Galactic astronomy:

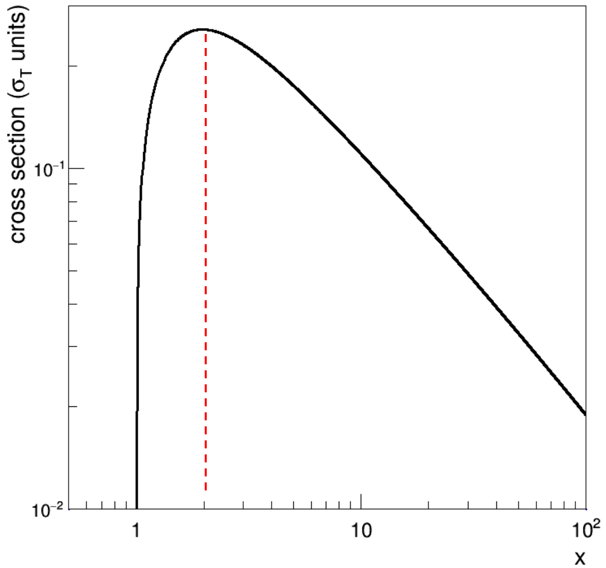
1) Point sources (SNRs…)
2) Diffuse fluxes
   (by detectors with large FOV, like HAWC, LHAASO, HiSCORE…):

- 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:

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

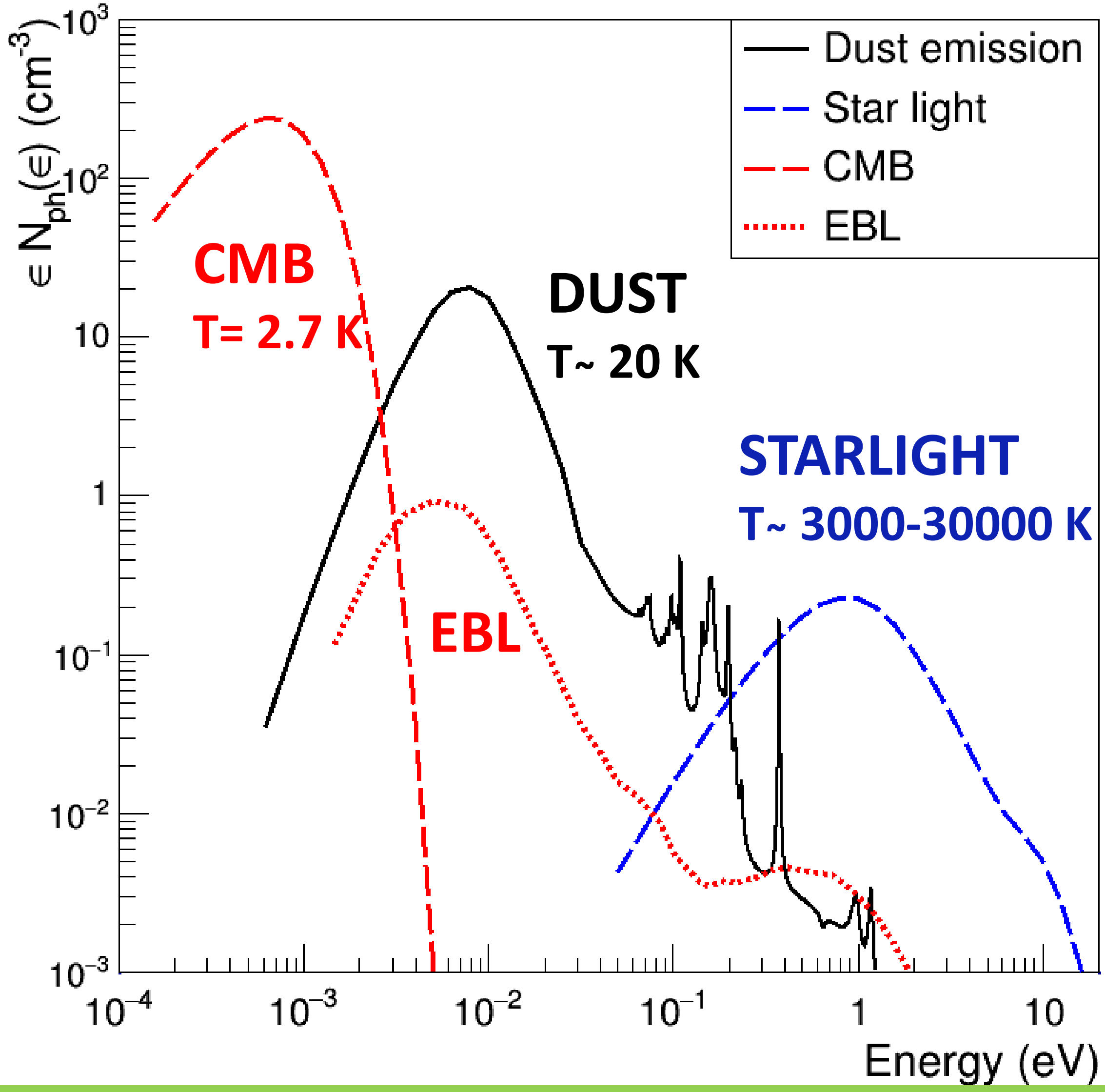
Maximum cross section for:

$$\frac{E_\gamma}{1\ \text{TeV}}\ \frac{\varepsilon}{1\ \text{eV}} = \frac{1.02}{1 - \cos\theta}$$

Flux attenuation:

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

Local radiation fields



Four radiation components

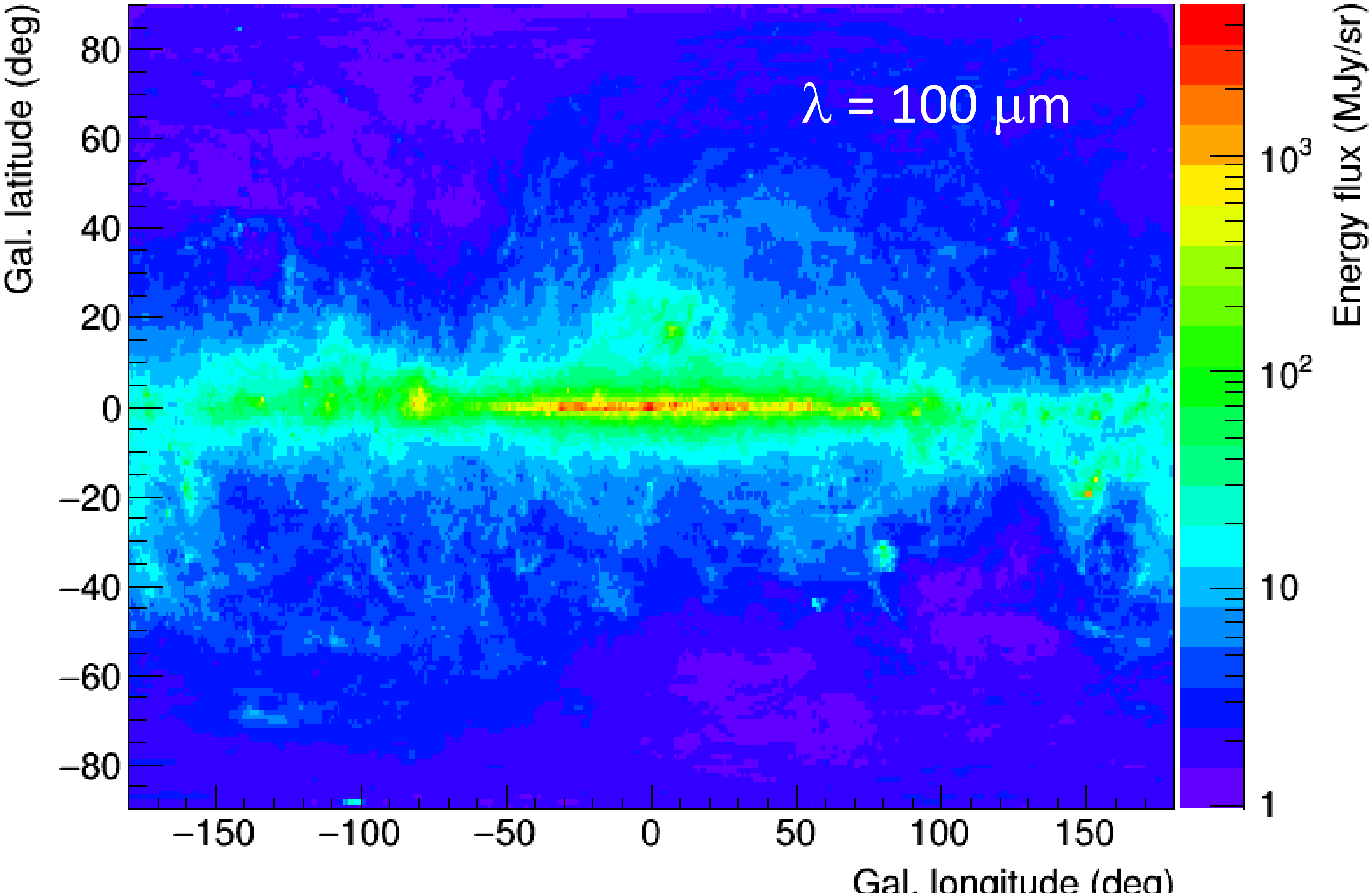
Galactic & anisotropic:

1) Starlight
2) Infrared dust emission

Extragalactic & isotropic:

3) Cosmic Microwave Background (CMB)
4) Extragalactic Background Light (EBL)

Infrared sky map by IRAS



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

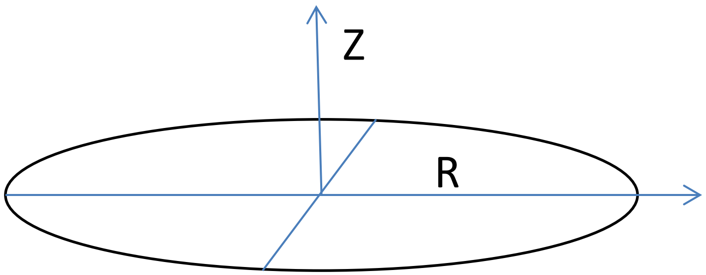
Dust emission model by *Misiriotis et al., A&A 417, 39, 2004* :

- "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:

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

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

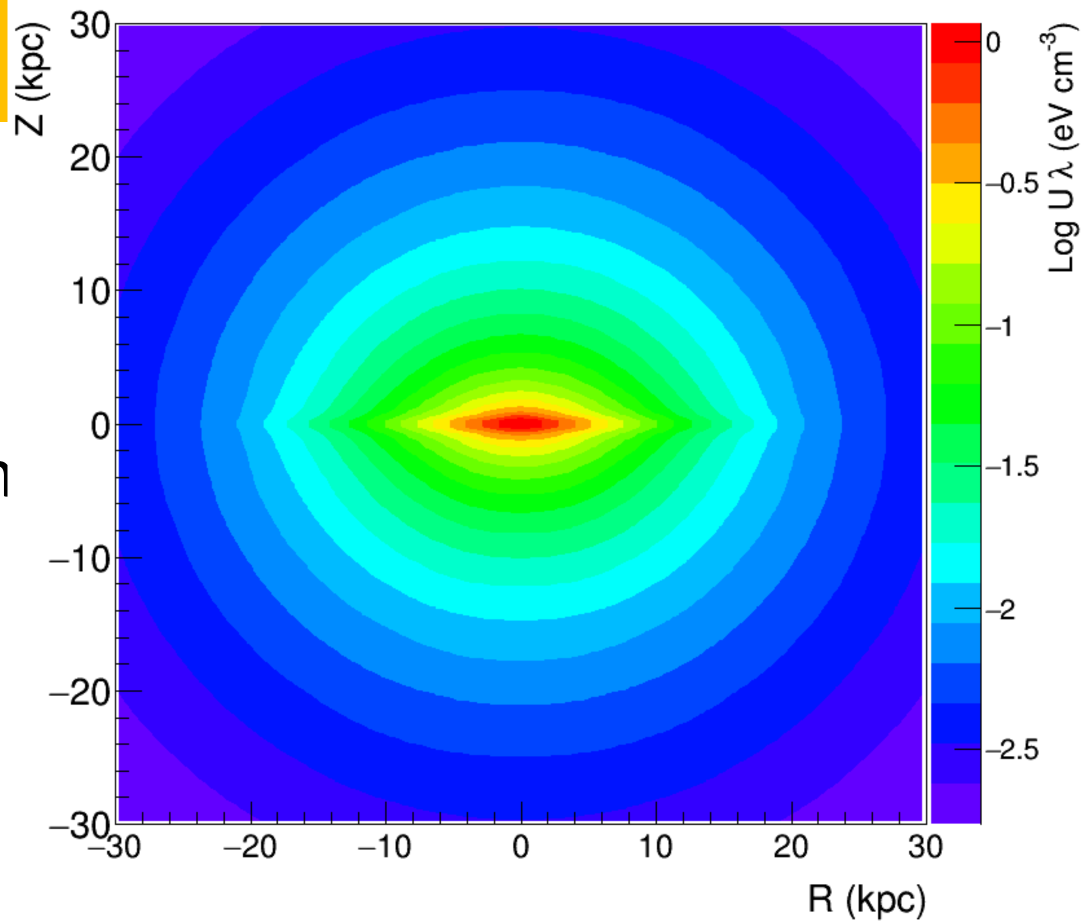
Cylindrical coordinates



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

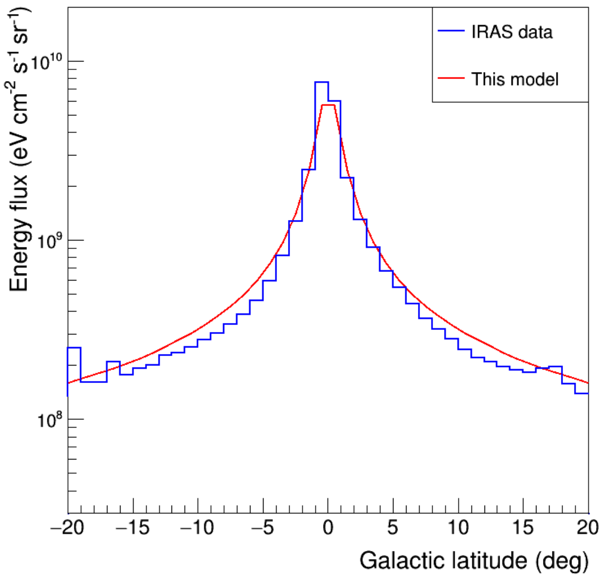
- infrared spectrum
- flux angular distribution

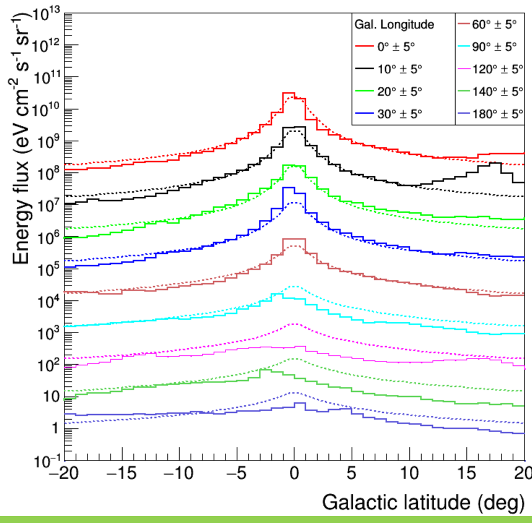
Energy density at 100 μm in the Milky Way

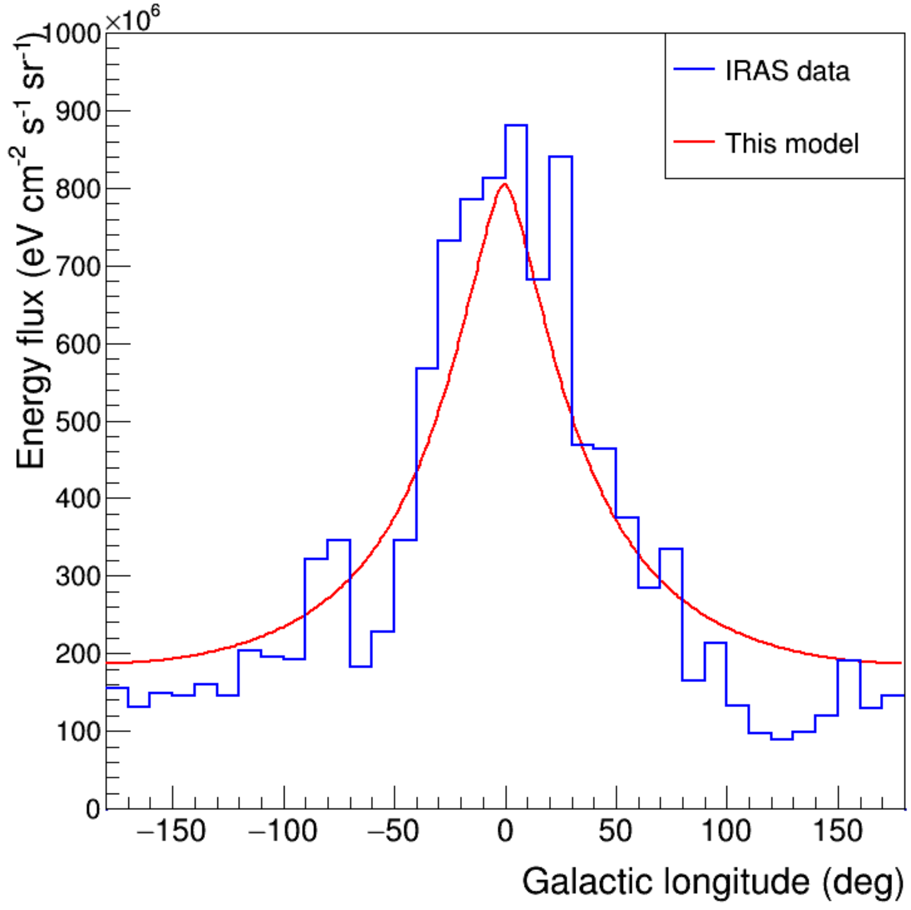


Model vs. data - 1

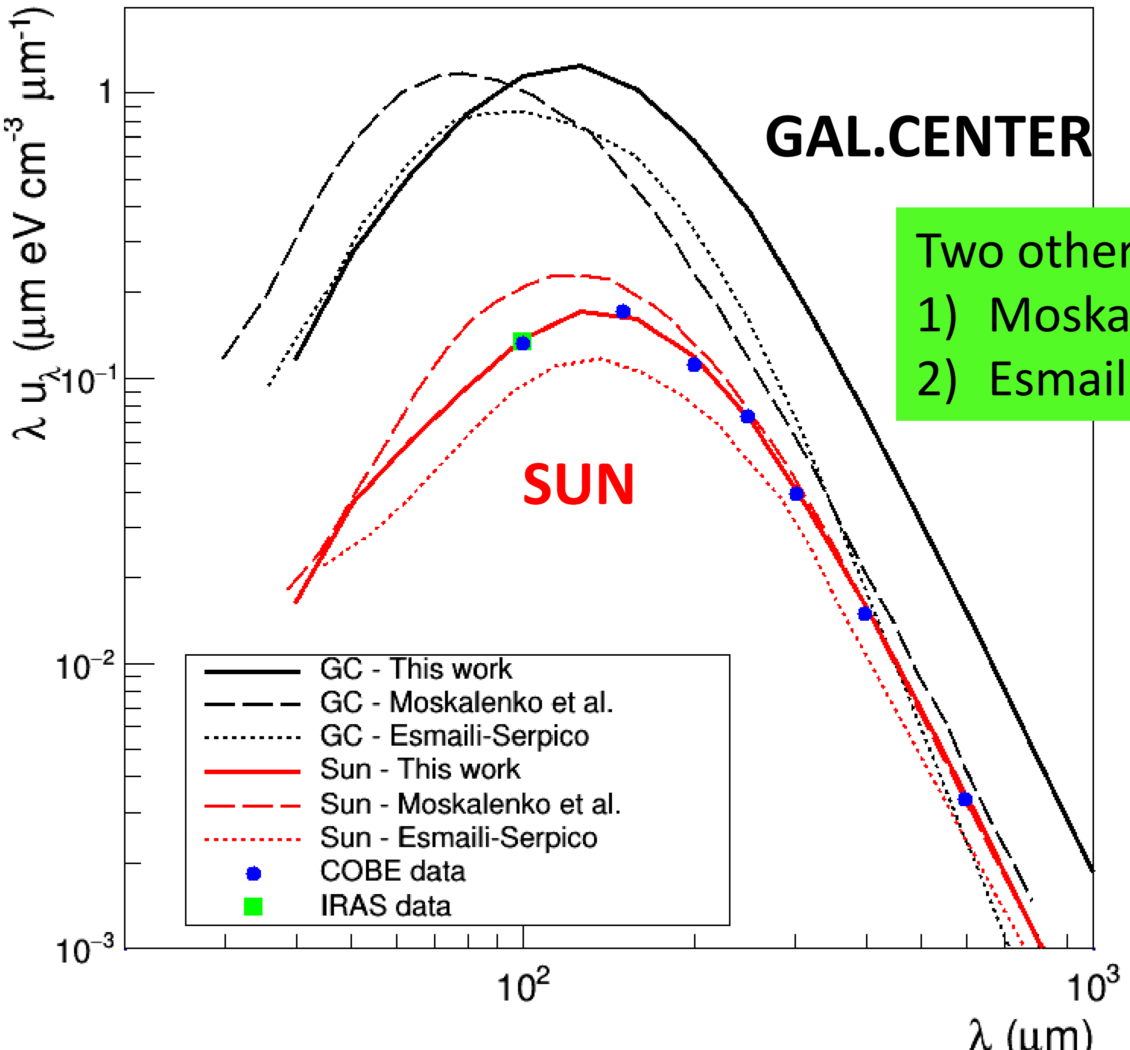
Latitude and longitude distributions at 100 μm





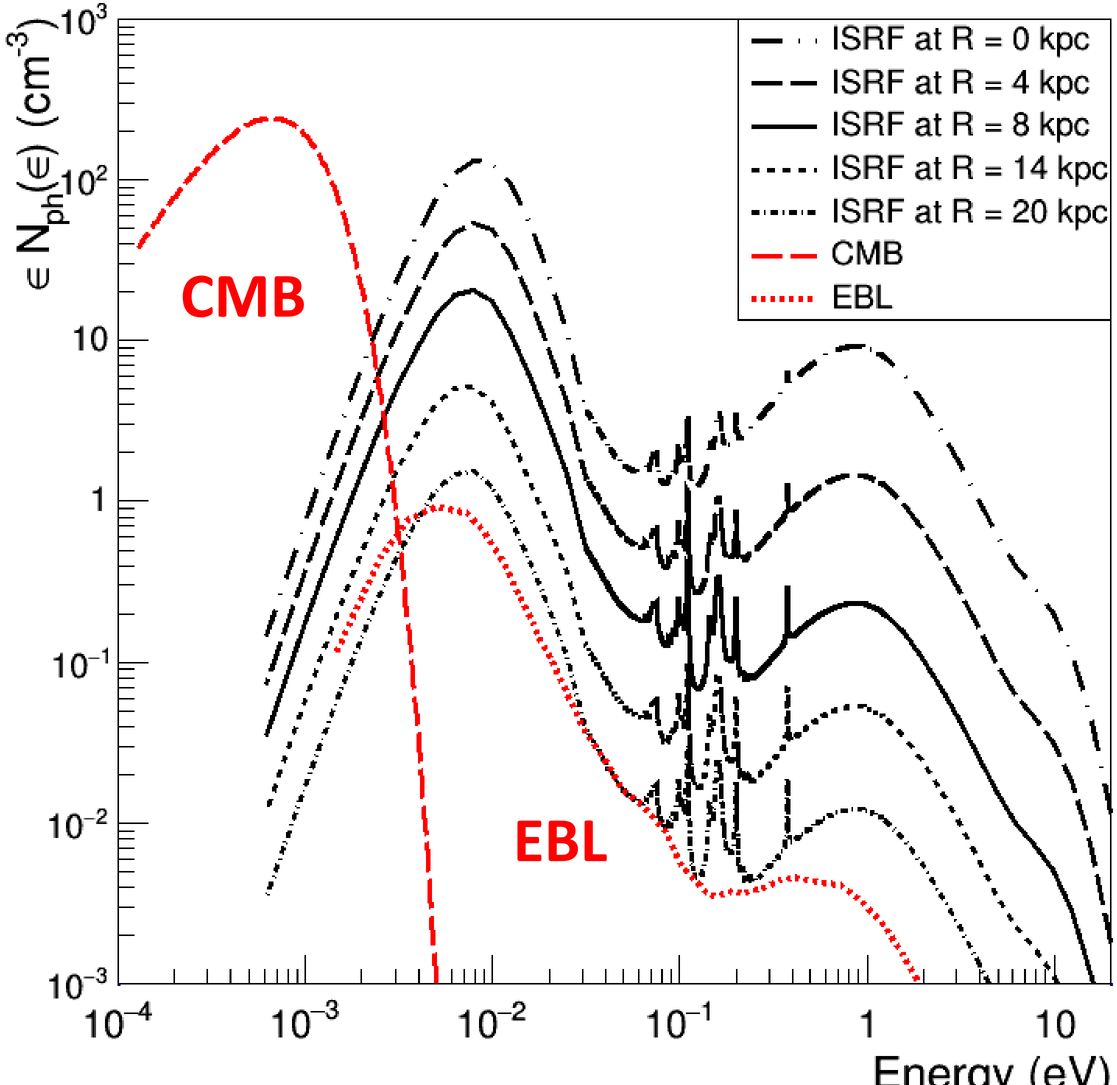


Model(s) vs. data - 2
Infrared spectrum

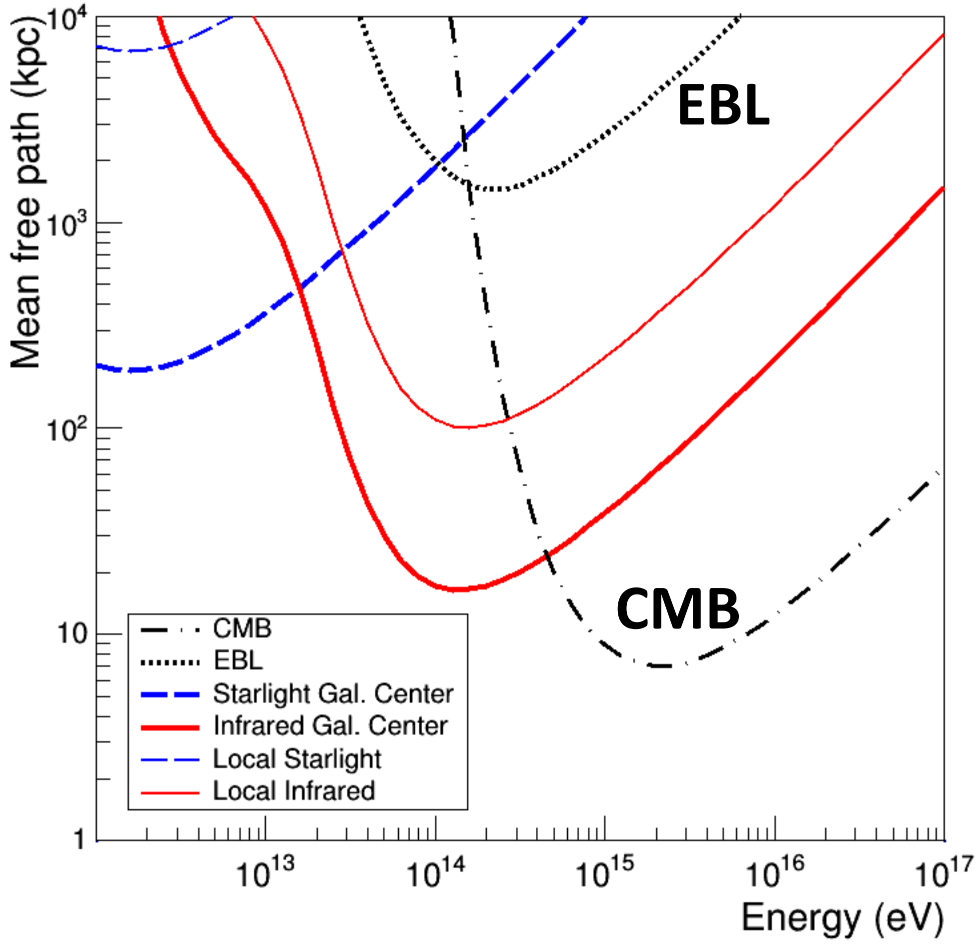


Two other models:
1) Moskalenko et al., 2006
2) Esmaili & Serpico, 2016

Radiation fields in the Galaxy

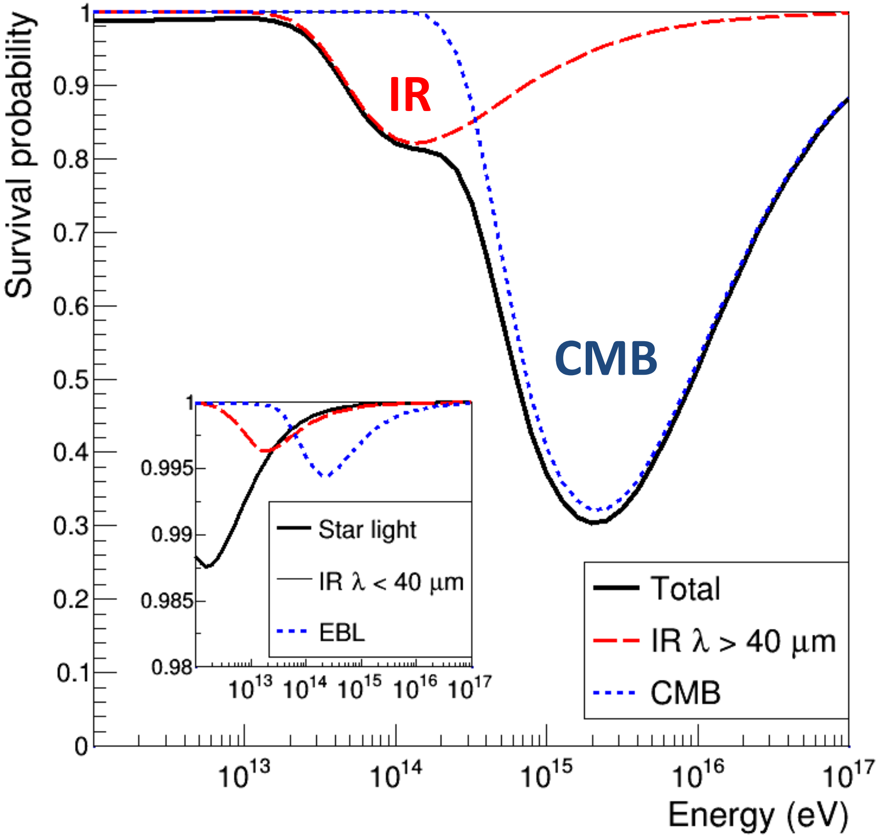


Gamma ray mean free path

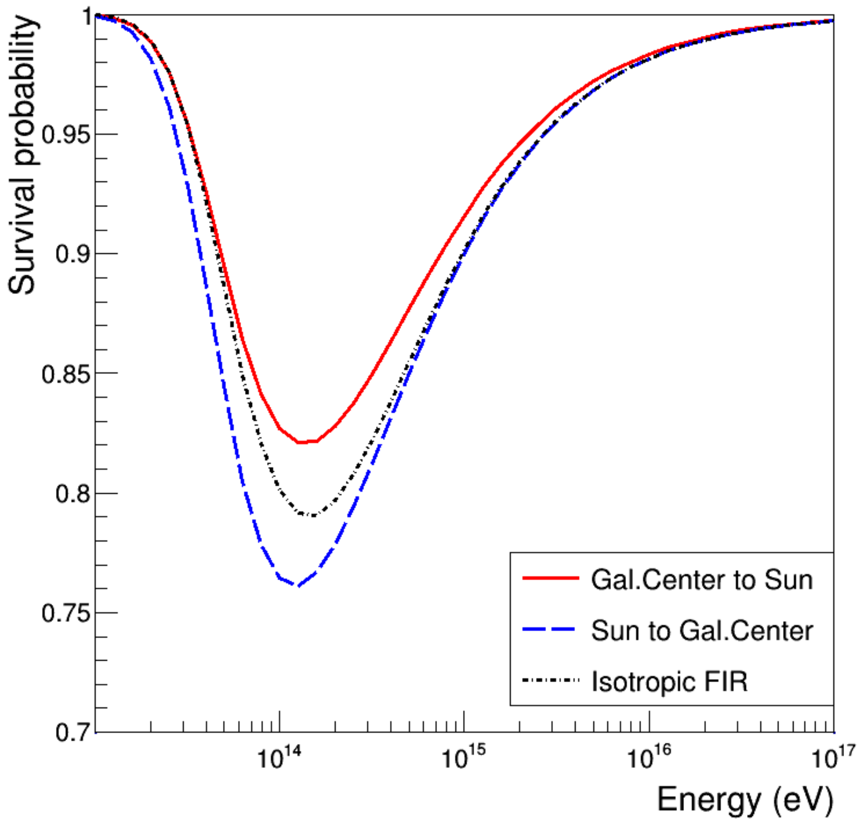


Survival probability for gamma rays from the Galactic Center

γ-rays from Galactic Center

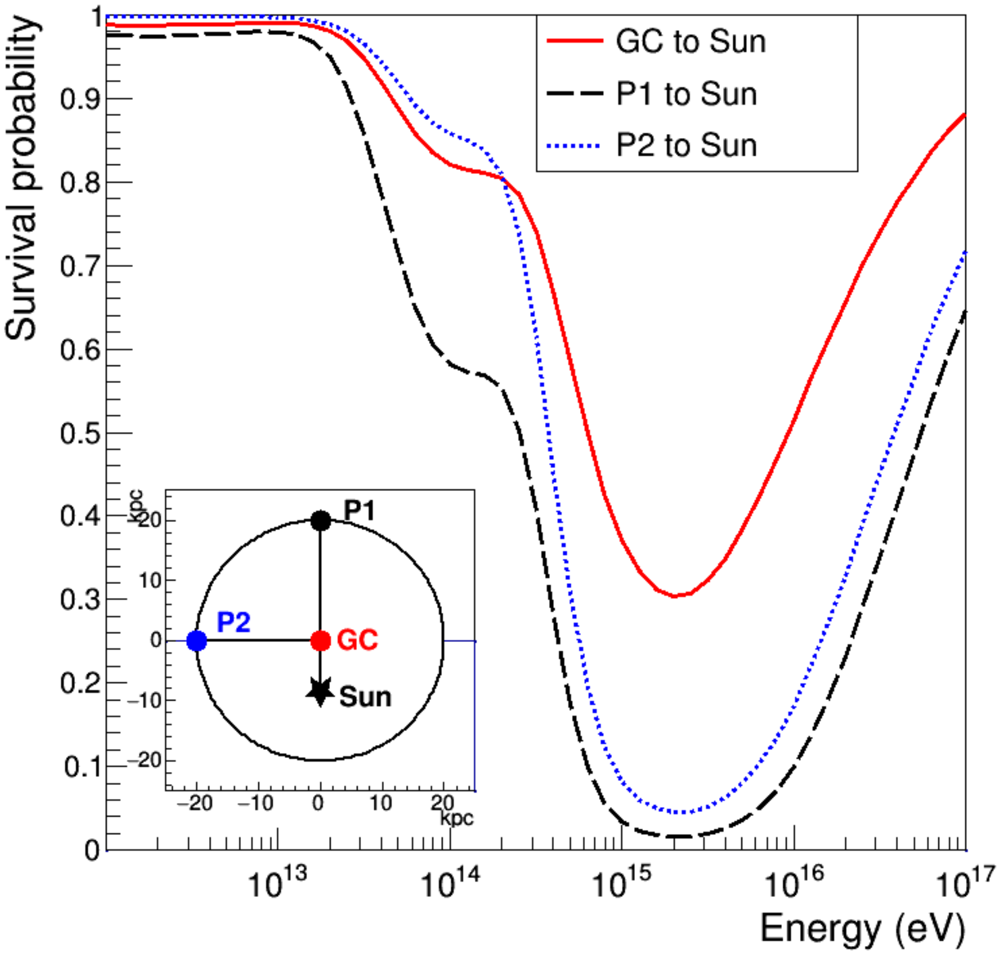


Anisotropy effect for the trajectory GC-Sun



Survival probability vs. gamma ray energy

Gamma rays from 3 source positions



Model description in:
Vernetto & Lipari, Phys.Rev.D 94, 063009, 2016

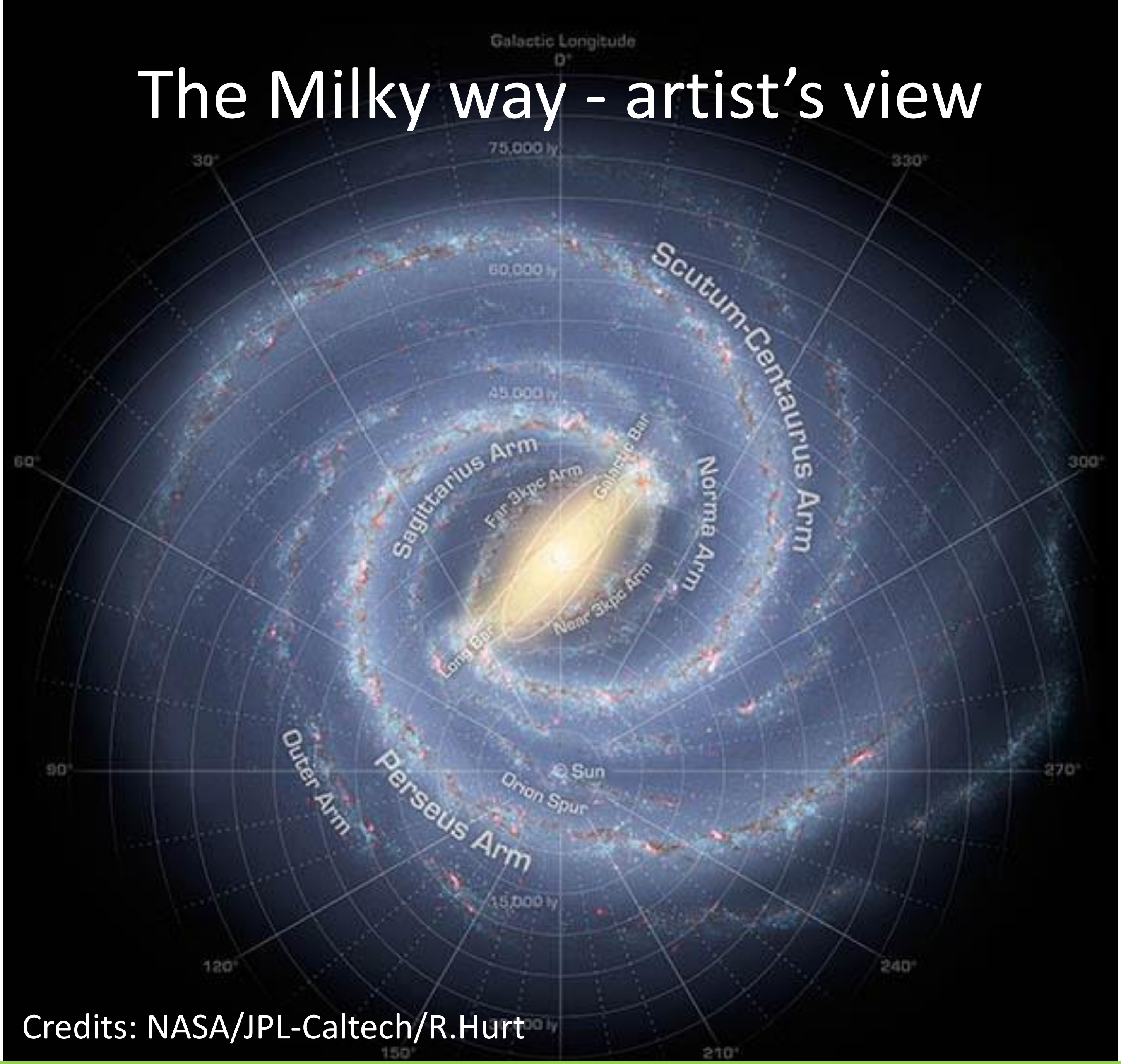
The model is particularly suitable to calculate the attenuation of diffuse gamma ray fluxes.

Some applications will be presented in the next talk by Paolo Lipari

Improving the dust model.....

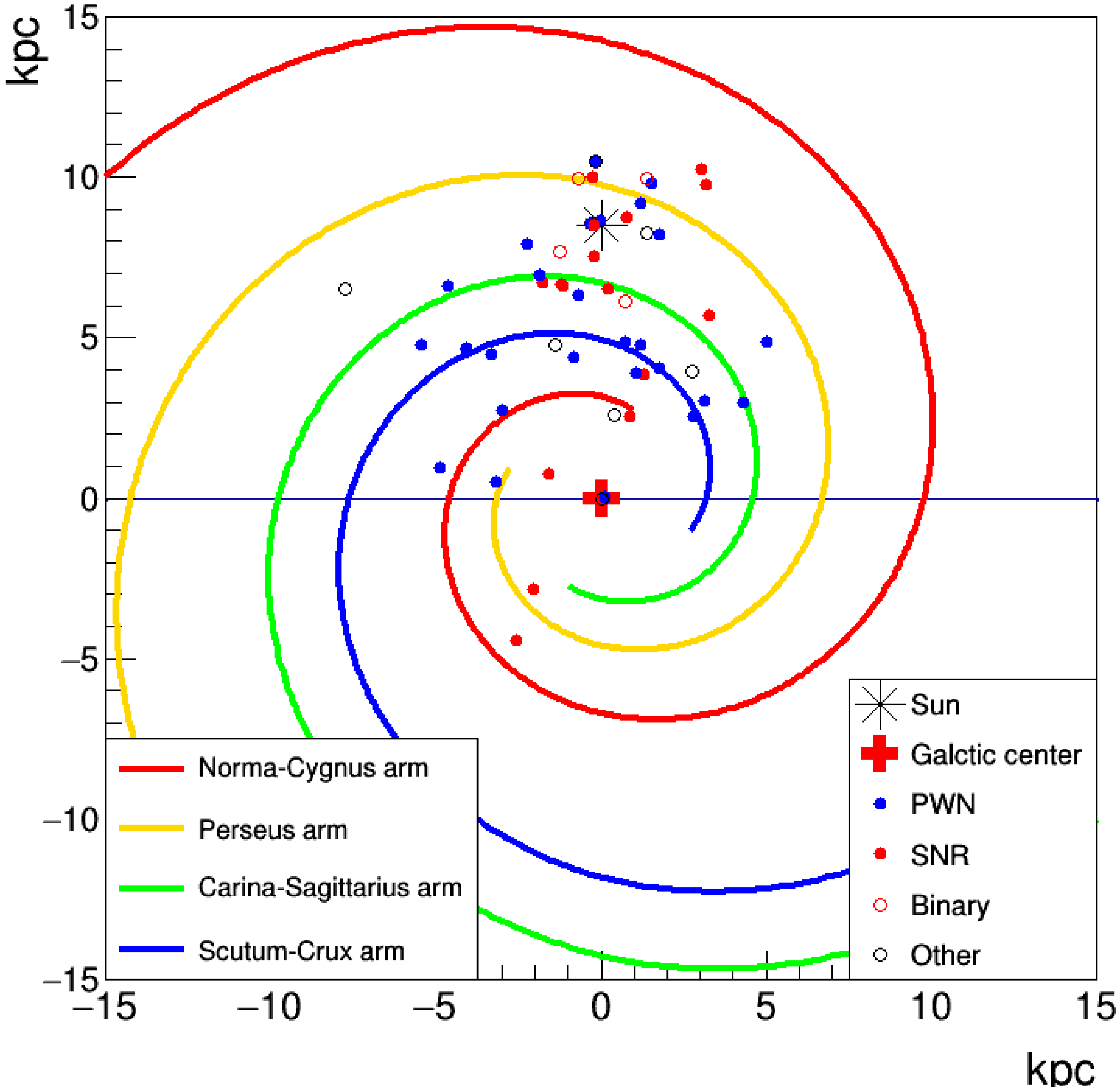
[work in progress]

The Milky way - artist's view



Credits: NASA/JPL-Caltech/R.Hurt

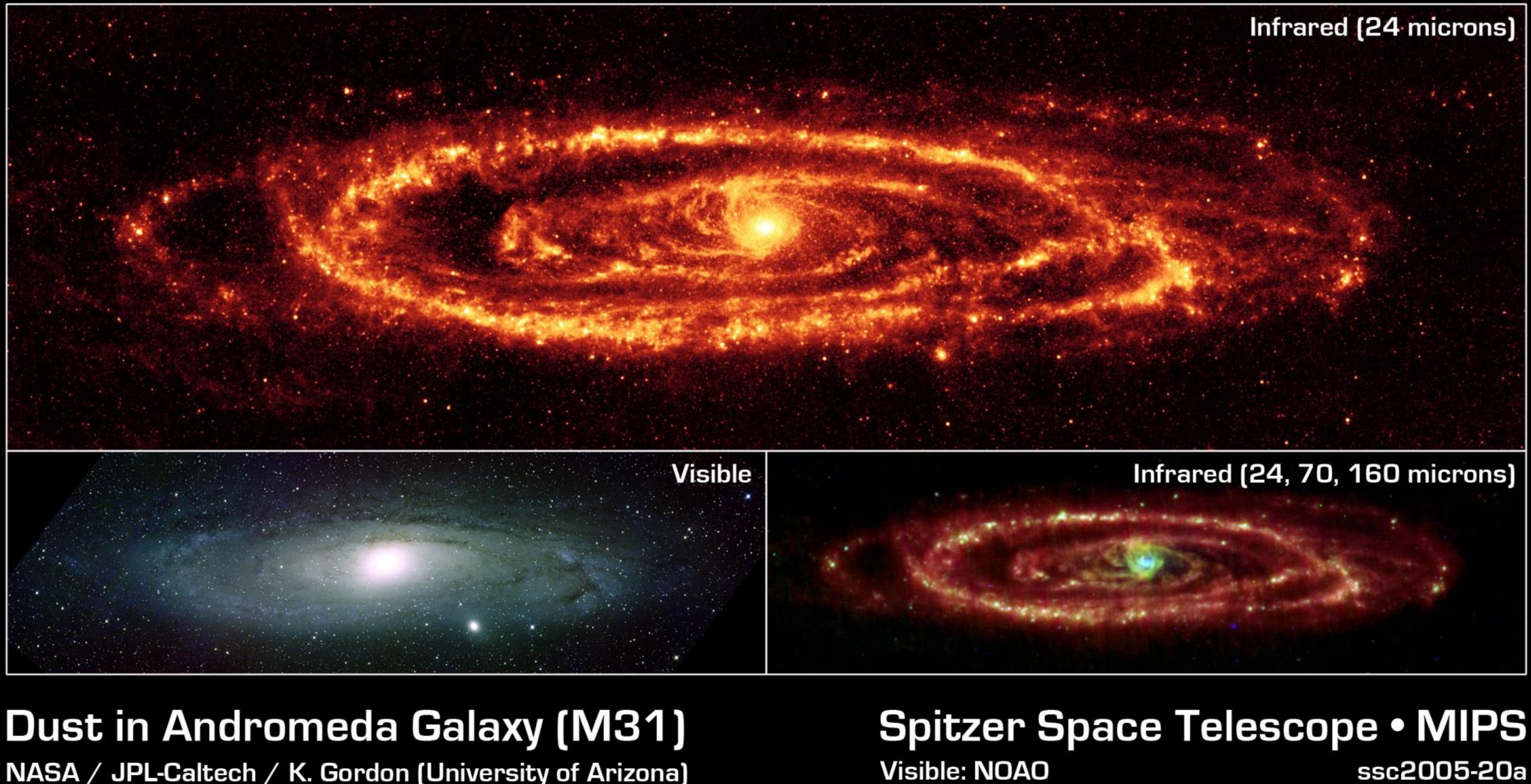
Galactic TeV sources



58 sources out of 103 with measured distance (from TevCat)

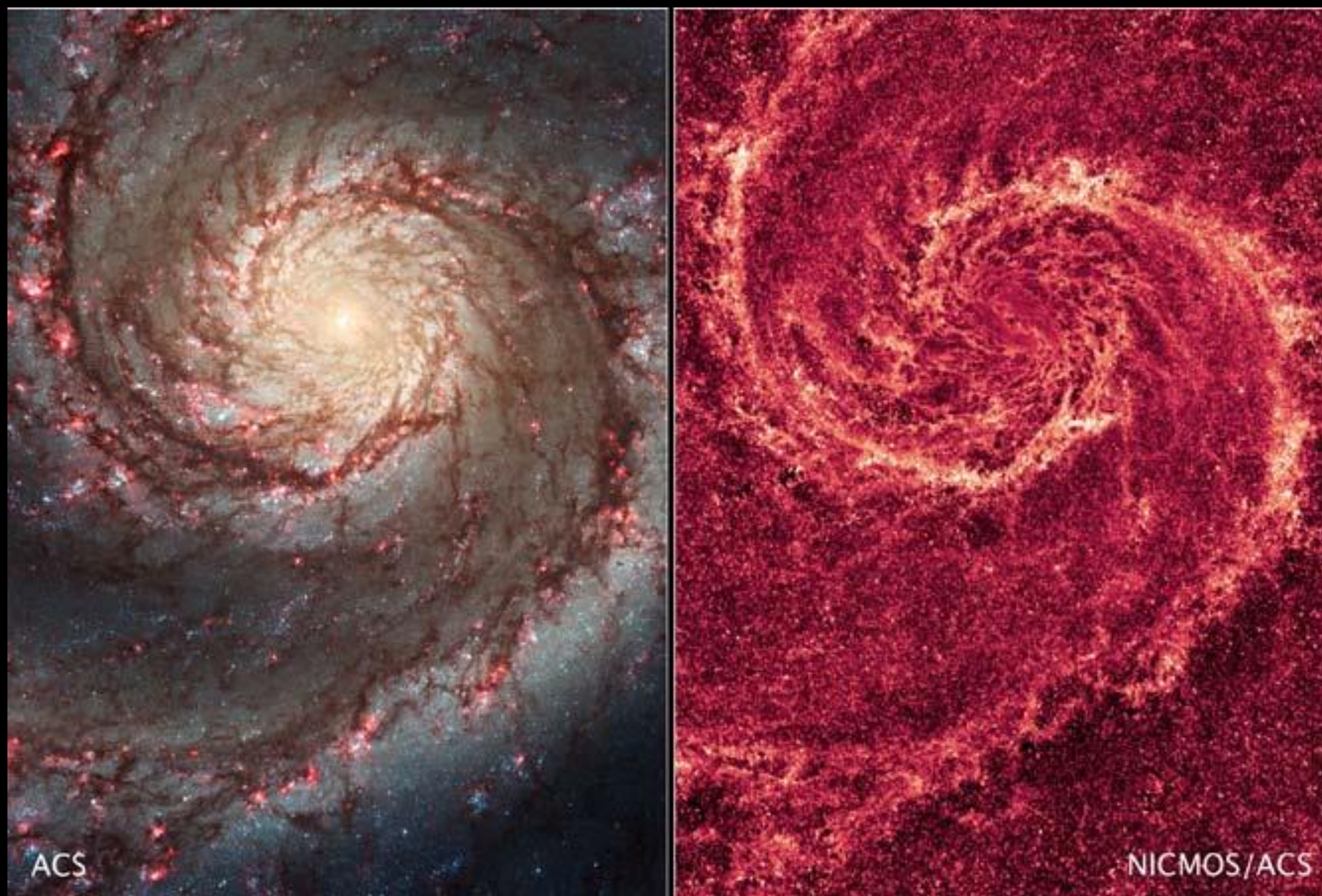
Spiral arms geometry from Higdon & Lingenfelter, 2013

Dust in Andromeda Galaxy



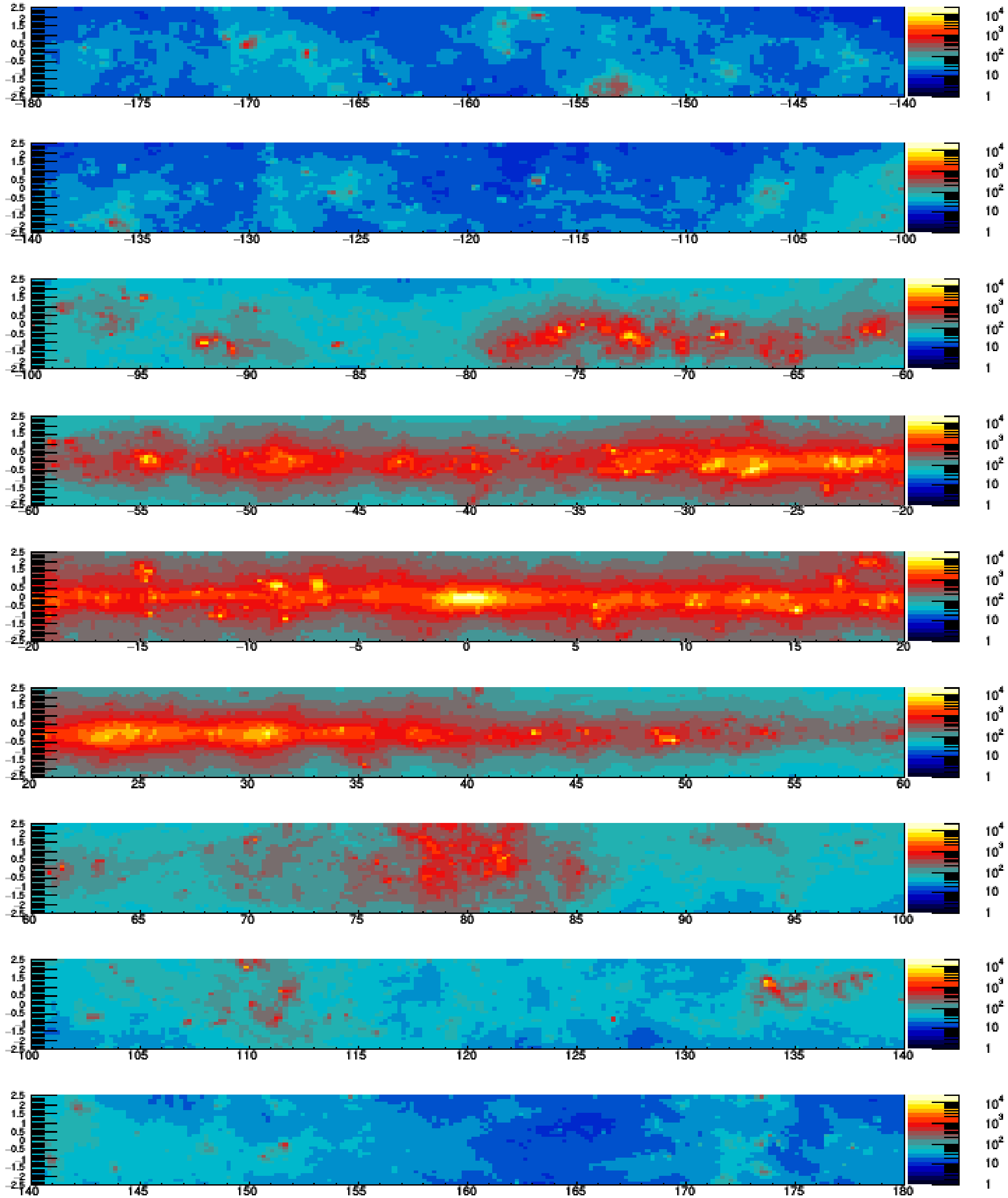
M51 - Whirpool Galaxy

M51 - Whirpool Galaxy



Visible   Near Infrared

by Hubble ST

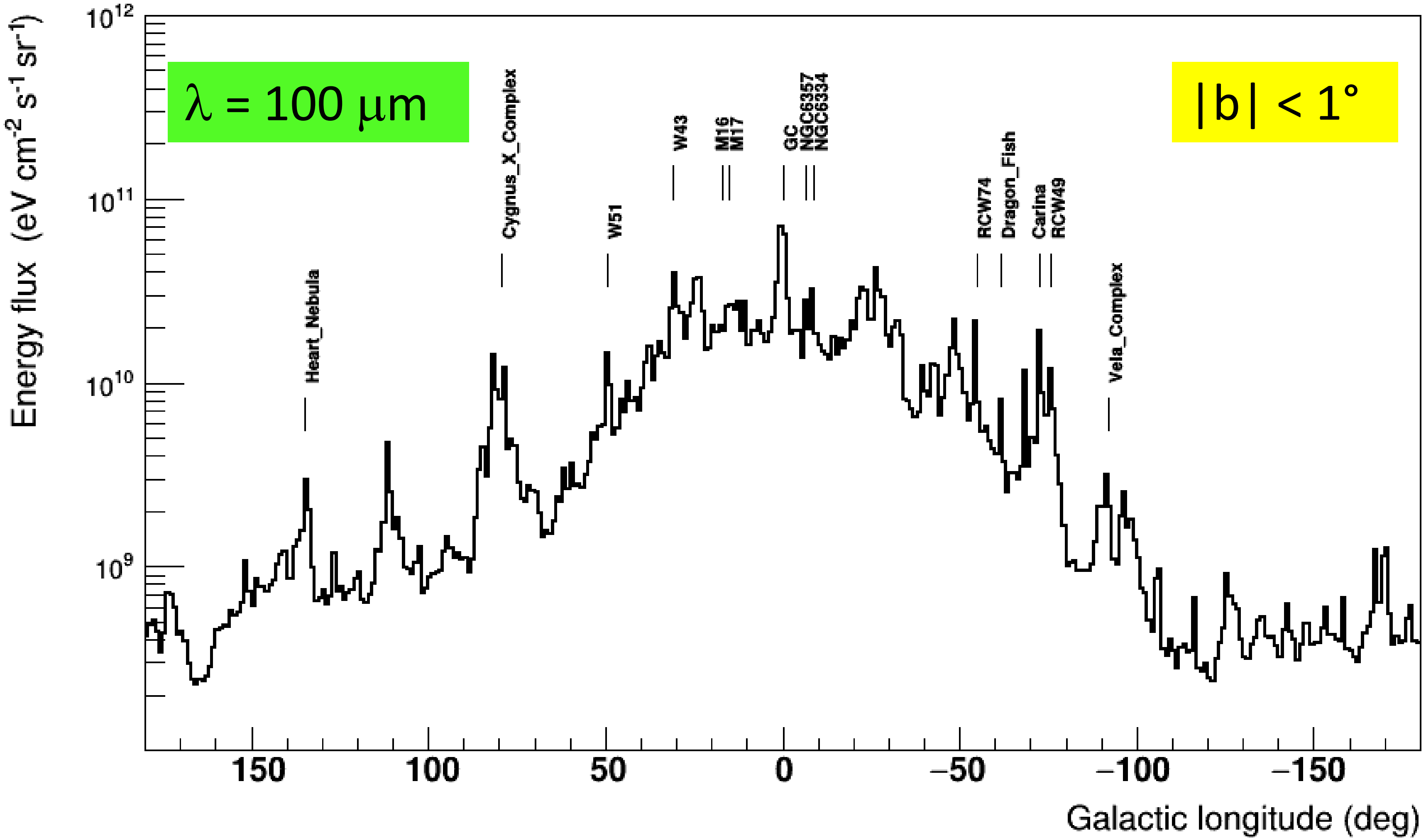


Galactic plane

IRAS

λ=100 μm

IRAS - Galactic longitude distribution



Ingredients to model the dust emission

Dust spatial distribution: disk + four spiral arms

1) Axisymmetric disk : exponential disk with a maximum emission at ~4 kpc, defined by a radial scale length and a scale height (including the disk flaring)

2) Spiral arms: four logarithmic spirals, defined by pitch angles, rotation, arms width and height

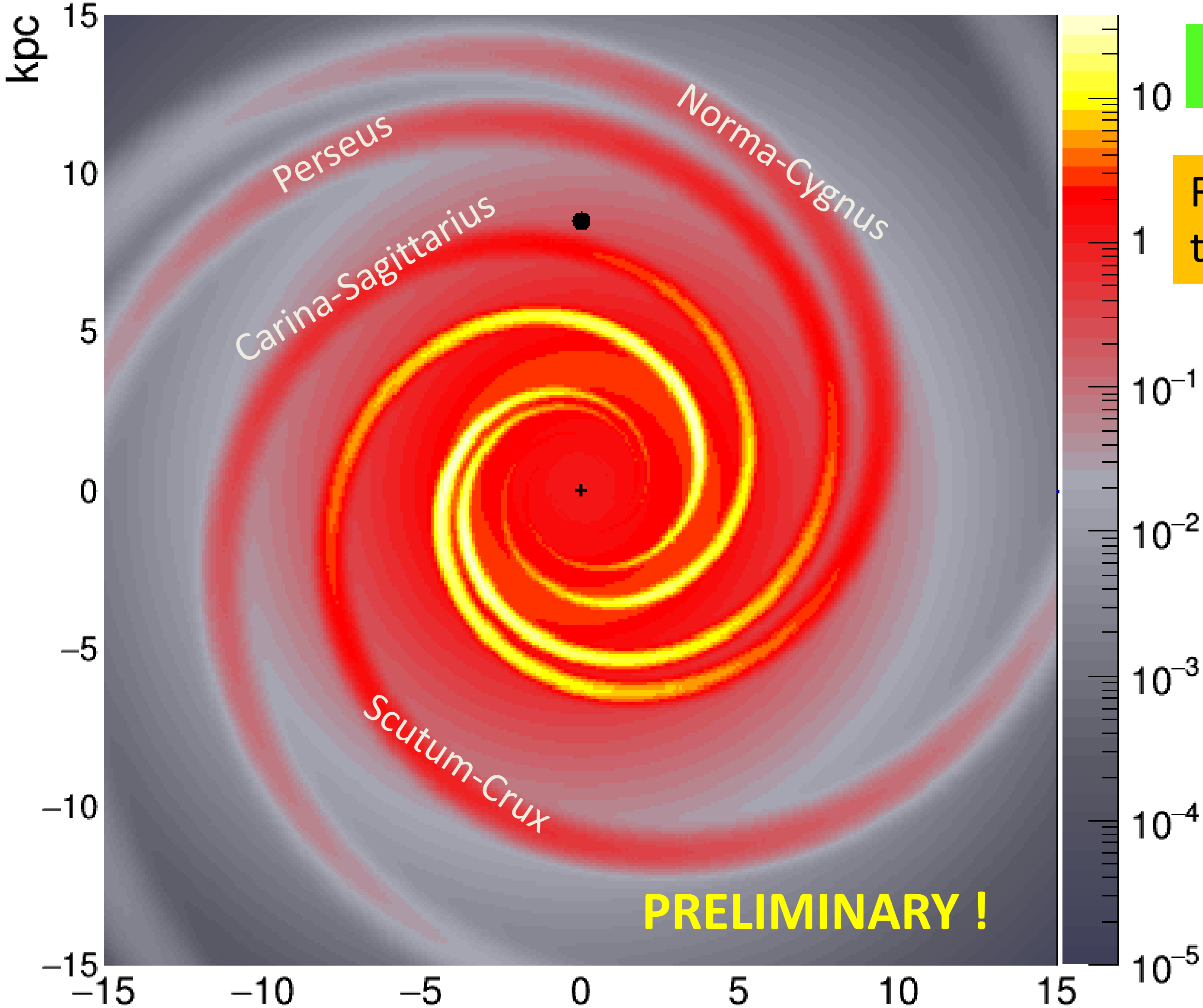
Data: measurements of HI [21 cm], CII [158 μm], NII [205 μm] lines

Dust temperature distribution

Temperature of the dust heated by diffuse starlight
Temperature of warm dust in Star Forming Regions in spiral arms

Data: Planck and IRAS measurements (λ = 60-850 μm)

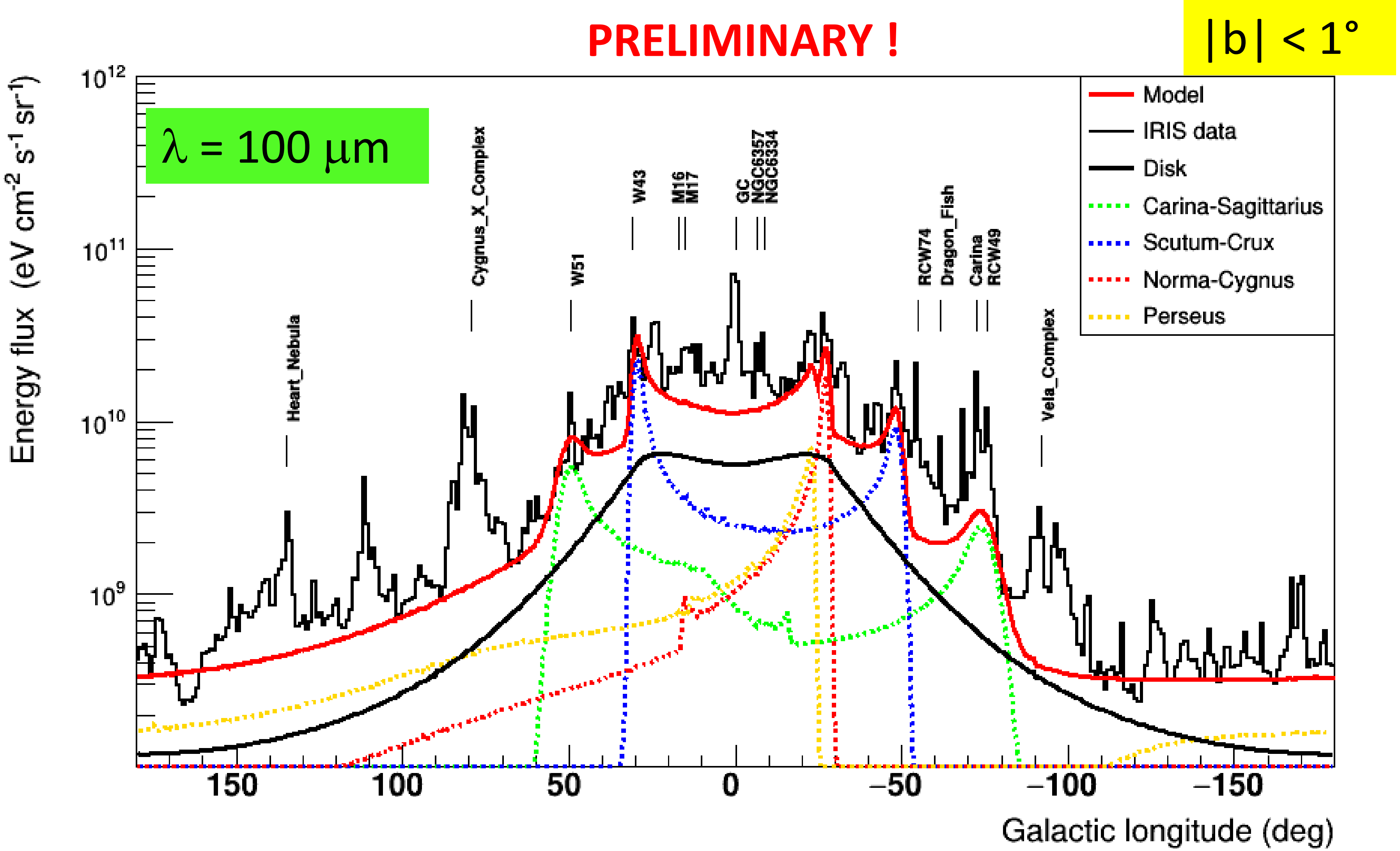
Infrared Galactic emission model



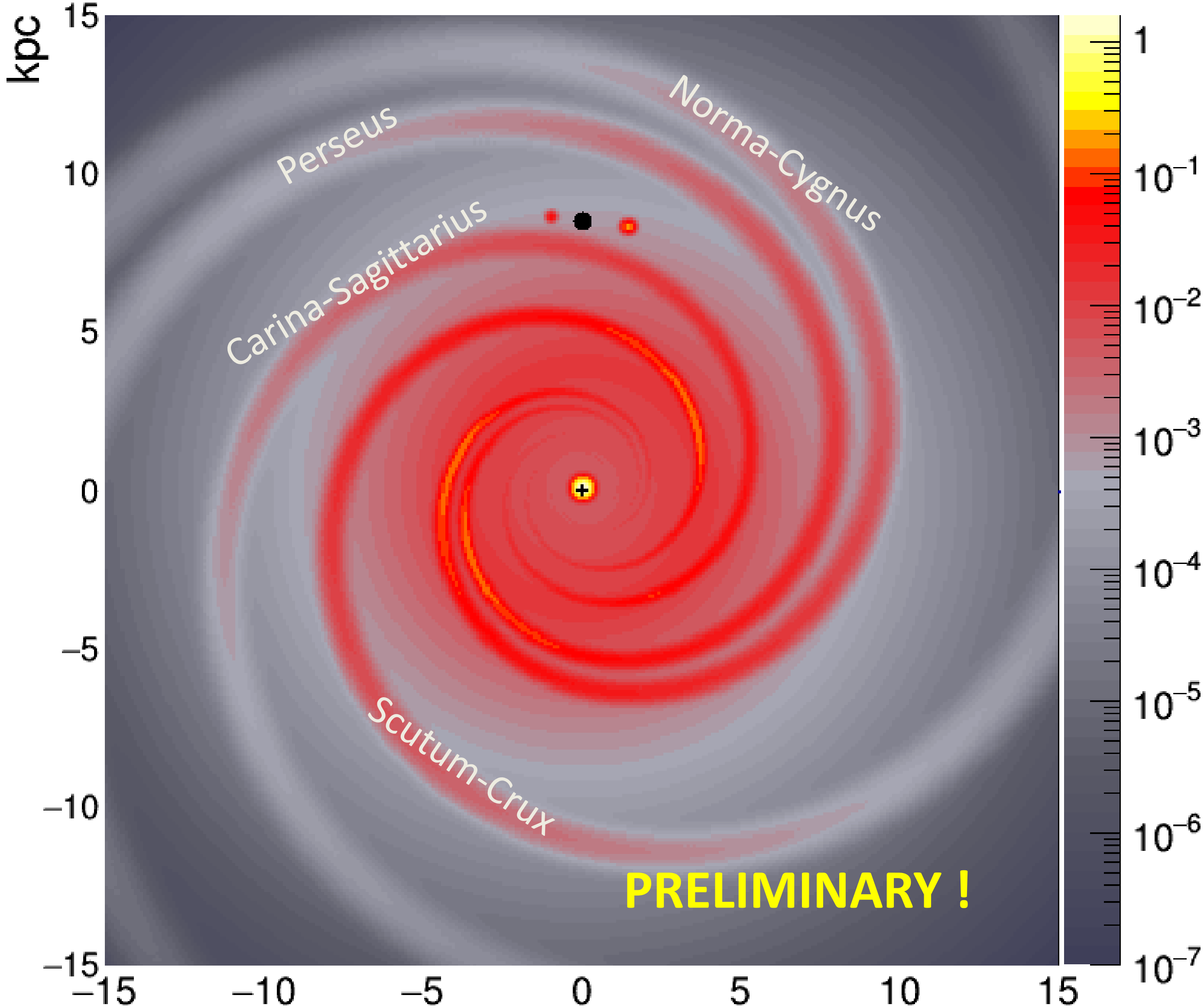
λ = 100 μm

Flux normalized to Gal.center

Data and model: longitude distribution



Infrared Galaxy emission model
+ Gal.Center, Cygnus X and Vela star forming regions



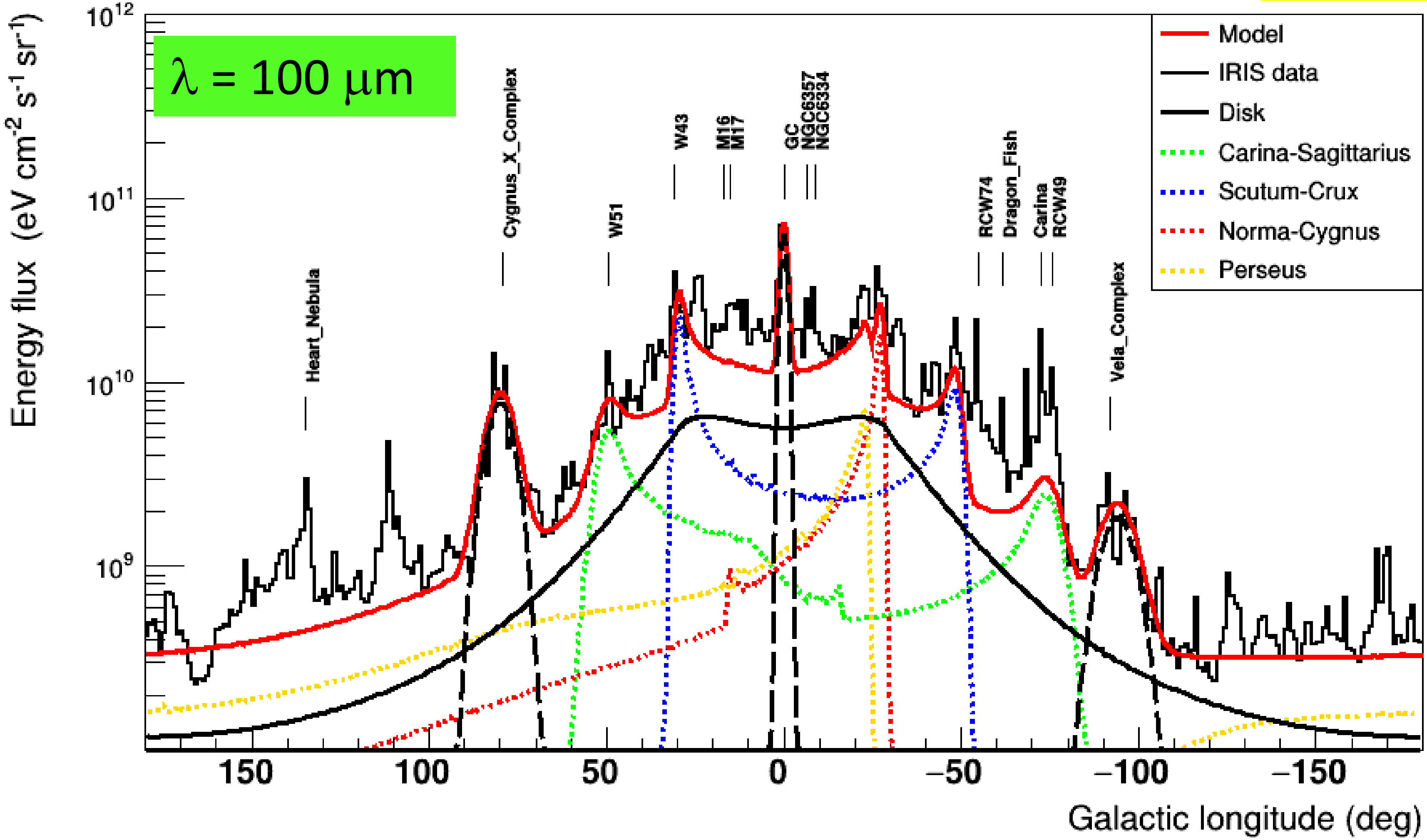
λ = 100 μm

Flux normalized to Gal.center

Data and model: longitude distribution

PRELIMINARY !

|b| < 1°



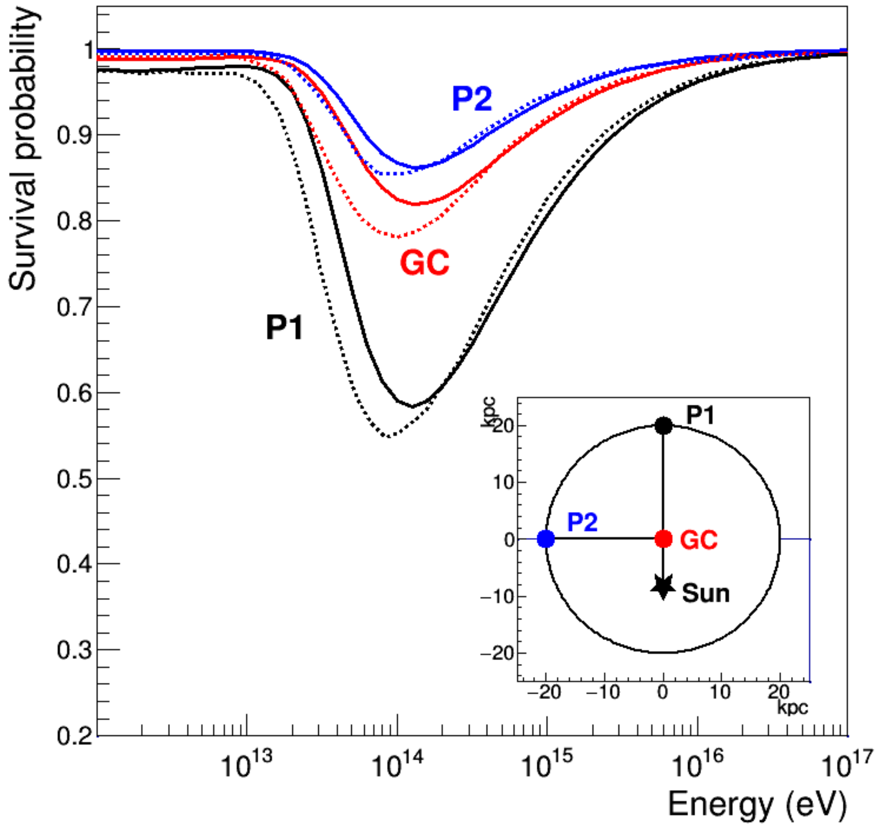
Conclusions

- In the energy range above 30 TeV the absorption of gamma rays in the Galaxy due to pair production must be taken into account for a correct interpretation of future data.
- The absorption exists but does not precludes Galactic gamma ray studies up to a few hundreds TeV. At higher energies only a fraction of the Galaxy is visible.
- We developed a simple model to calculate the absorption for any gamma ray trajectory. The model is described in a paper and can be easily used by anyone. Alternatively, we can provide tables with absorption coefficients.
- The model is able to evaluate the global absorption of diffuse gamma ray fluxes. It can also be used to calculate, in a more approximate way, the absorption of the flux from an individual source.
- A more detailed model of the dust distribution in the Galaxy is in progress, to evaluate more precisely the effects of absorption for single sources.

Backup slides

Survival probability: models comparison

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



Solid lines: our model
Dotted lines: Esmaili & Serpico