HARD X-RAY/SOFT γ-RAY OBSERVATIONS OF THE GALACTIC DIFFUSE EMISSION WITH INTEGRAL/SPI

- Diffuse continuum emission spectrum and spatial morphology
- Comparison with GALPROP modeling

L. Bouchet, E. Jourdain, J.-P. Roques
Université de Toulouse, UPS-OMP, IRAP, Toulouse, France
A. W. Strong
Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
T. A. Porter, I. V. Moskalenko
Hansen Experimental Physics Laboratory, Stanford University, USA

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SPI SPECTROMETER (20 keV – 8 MeV) ONBOARD INTEGRAL OBSERVATORY

SPI is a spectrometer which is endowed with an imaging system sensitive both to point sources and extended/diffuse emission.

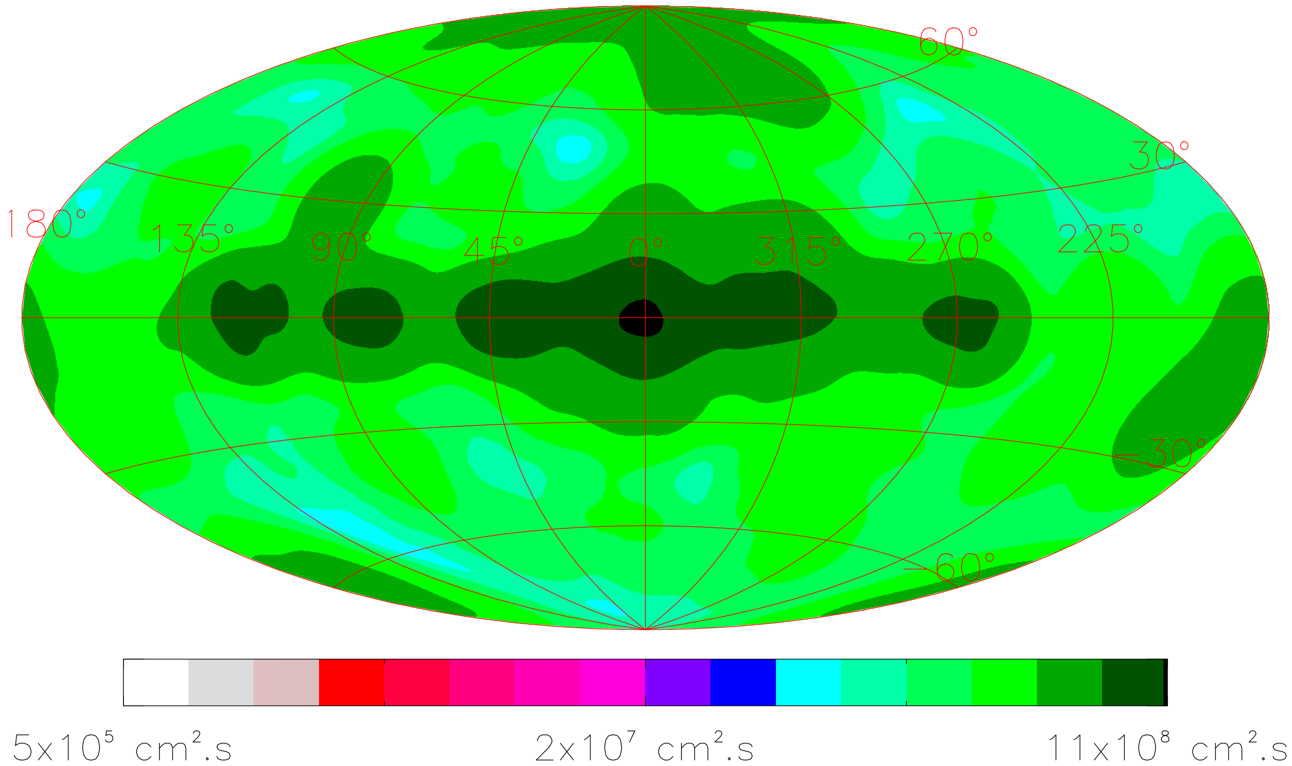
- Non-typical coded mask imaging system with a 30° FoV and 19 Ge detectors ($\Delta E/E$=3 keV @1.3 MeV)
- Imaging relies on the dithering observation strategy

STUDY THE HARD X-RAY/SOFT γ-RAY "DIFFUSE" EMISSION

Process 6 years of data simultaneously through a system of equations

- Disentangle : background, point sources emission (light curves) and "diffuse" emission

INTEGRAL/SPI exposure surface (2003-2009)



~ 1.1×10^{8} s livetime

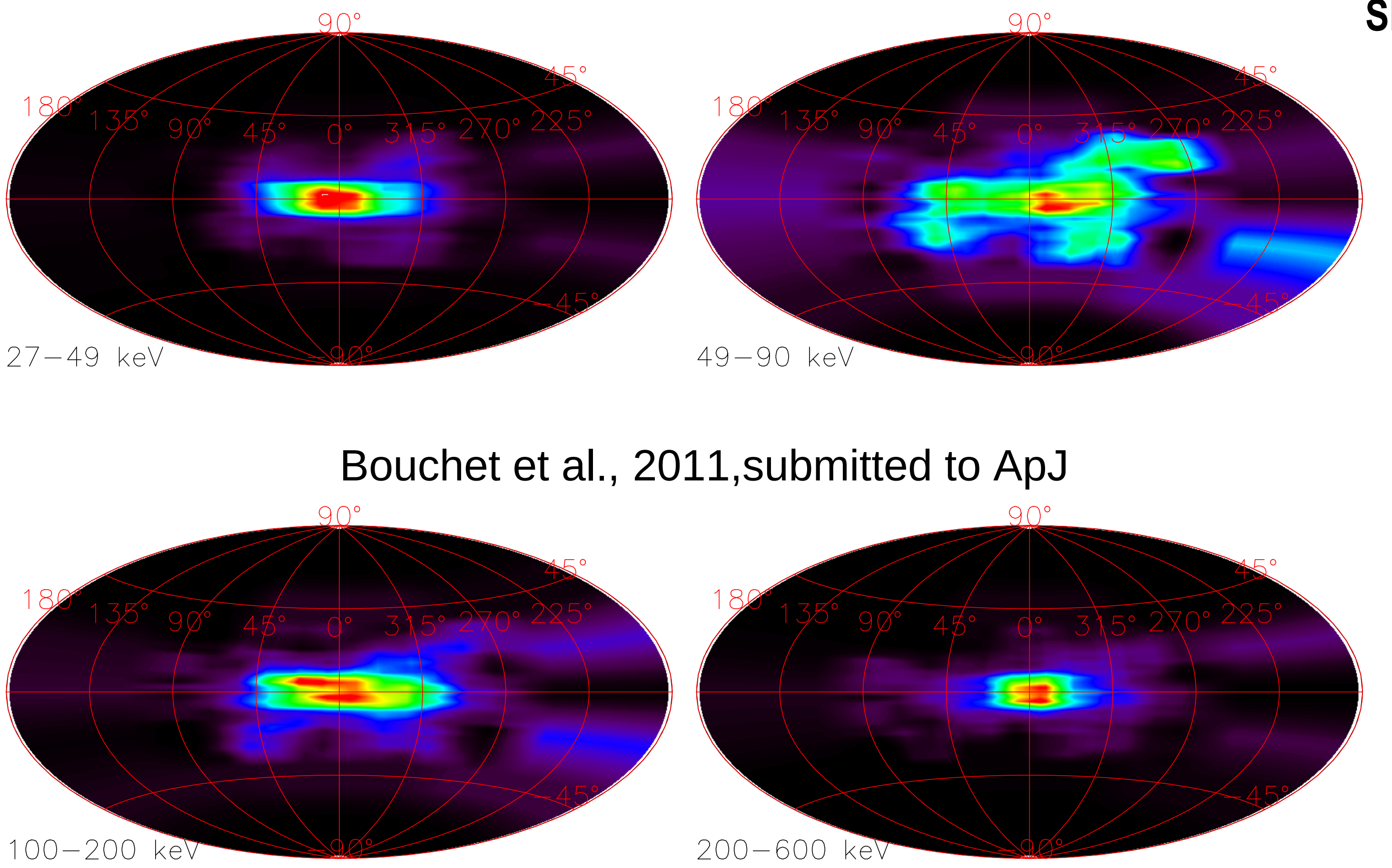
~ 40000 exposures (pointings or viewing periods of ~2800 s).

HARD X-RAY/SOFT γ-RAY DIFFUSE EMISSION

- Point sources dominate the Milky Way (20-200 keV) emission, “diffuse” interstellar emission is weaker than previously reported (Lebrun et al., 2004)
- The annihilation radiation dominates above 300 keV and reaches a maximum at 511 keV

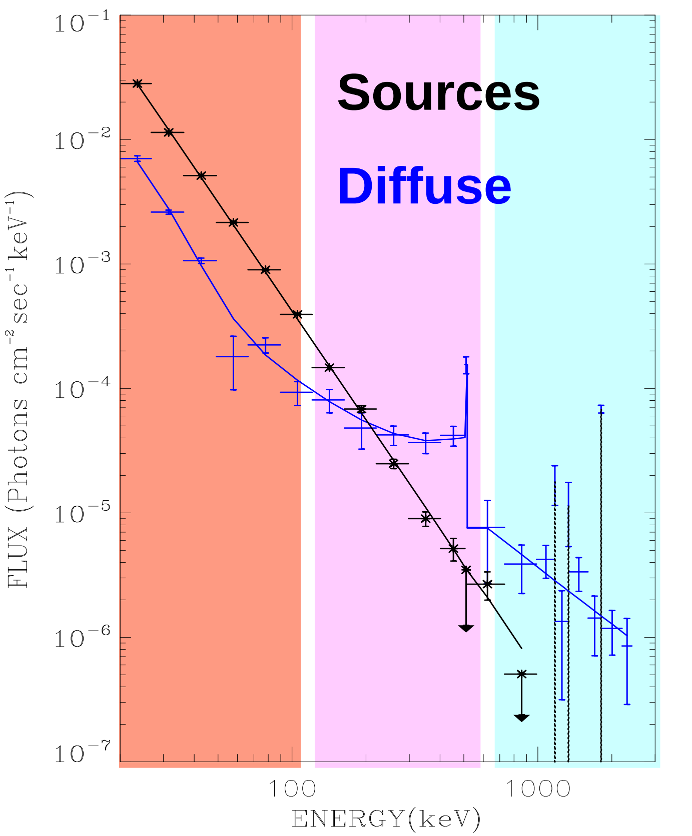
6 YEARS OF OBSERVATIONS :

270 sources in the 25-50 keV, 129 in the 50-100 keV, 68 above 100 keV



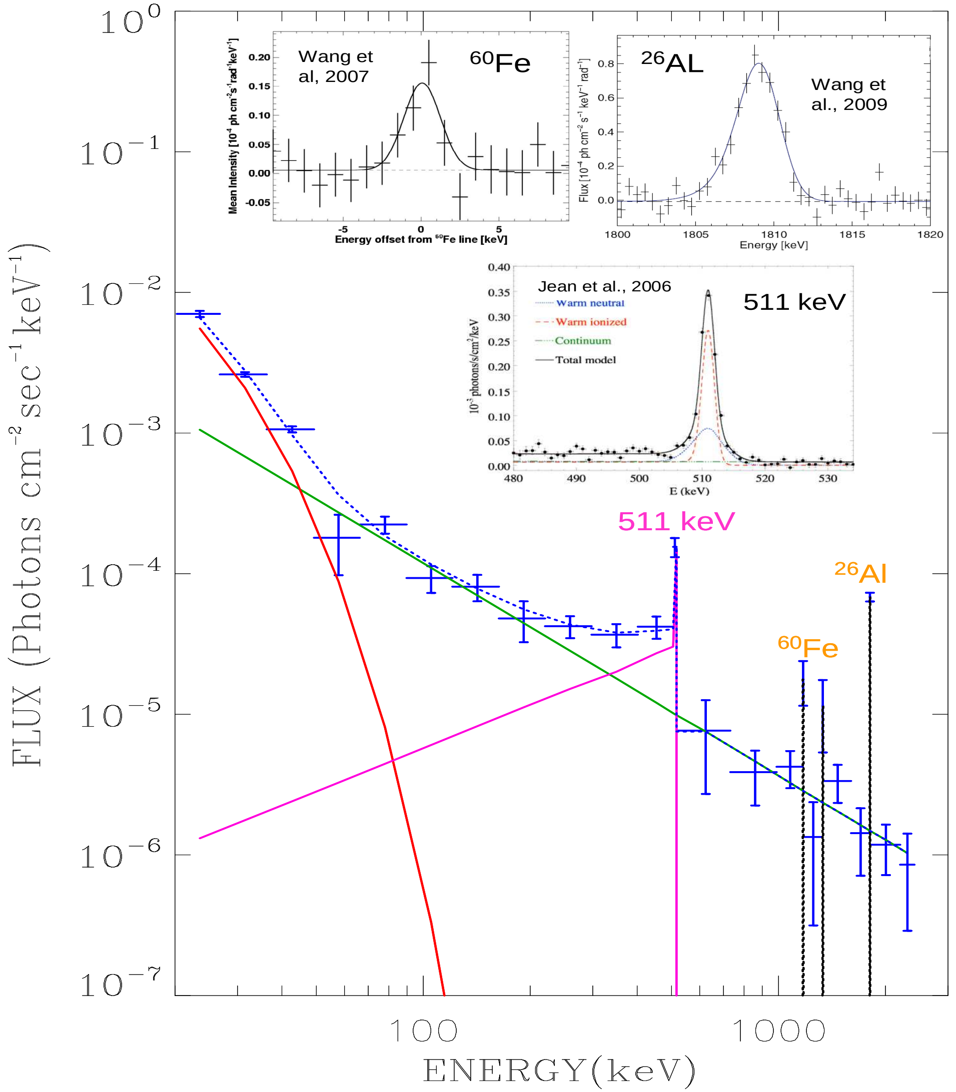
Bouchet et al., 2011,submitted to ApJ

SPI RADIAN (|l| < 30°, |b|<15°) SPECTRUM



DIFFUSE EMISSION

GALAXY (|l| < 30°, |b|<15°) **SPECTRUM**



Positron Astronomy

511 e^+e^- keV line & positronium continuum

Morphology (Weidenspointner et al., 08, Bouchet et al., 10, Churazov et al., 10)

Bulge : 3°+ 12° FWHM Gaussians

F_{511} ~10^{-3} ph.cm^{-2}.s^{-1}

Disk : ~1.7 x 10^{-3} ph.cm^{-2}.s^{-1}

Positronium fraction f ~ 100%

Spectroscopy (Churazov et al., 04 & 10, Jean et al., 06)

Galactic radioactivity
(Diehl et al., 04, Harris et al., 07, Wang et al., 07,09)

Inner Galaxy

^{60}Fe, F_{mean}~4x10^{-5} ph.cm^{-2}.s^{-1}
^{26}AL, F~3.1x10^{-4} ph.cm^{-2}.s^{-1}

^{60}Fe/^{26}Al ~18 %

CVs population (E < 100 keV)

“Unresolved” sources population which contains mainly CV’s and coronally active stars (Krivonos et al., 07)

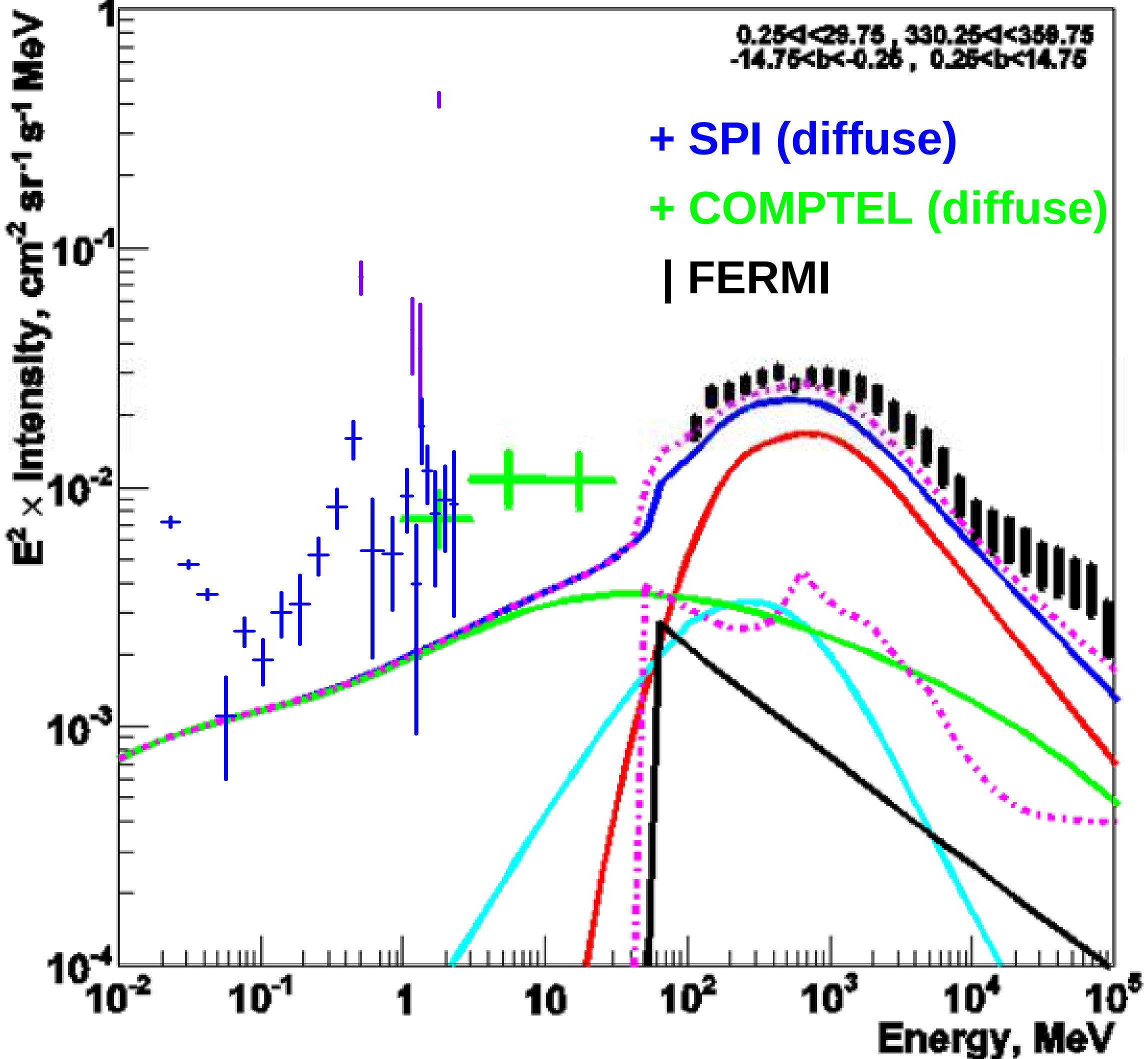
Diffuse continuum : mainly interstellar particle interaction

Power law α ~ 1.5

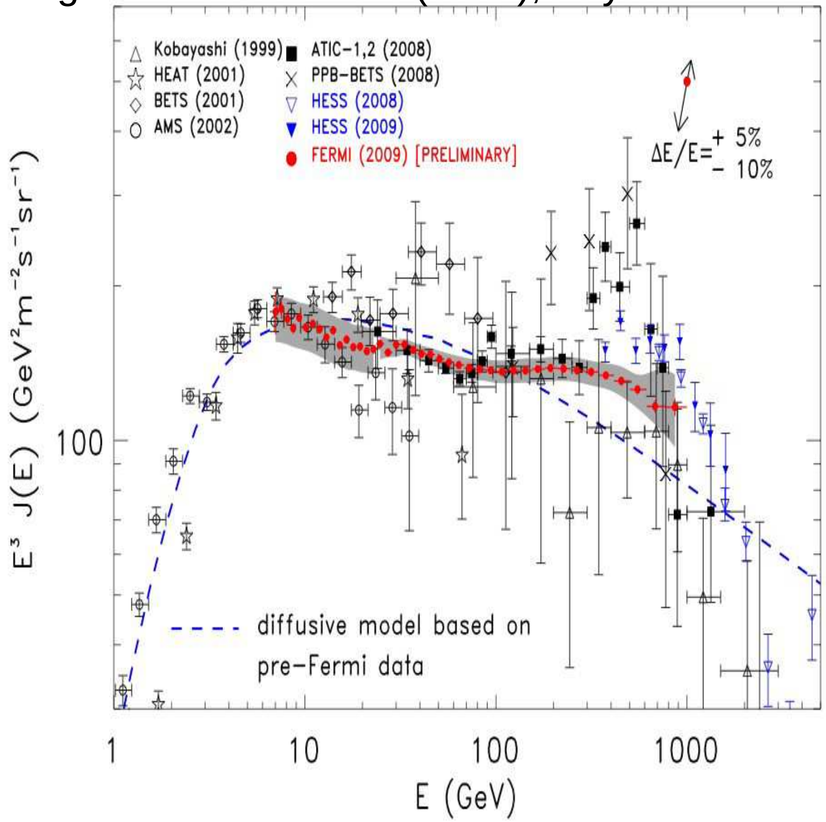
Diffuse X-rays/γ-rays from inner Galaxy

GALPROP code e.g. "cosmic-ray propagation code" (I. Moskalenko talk)

galdef ID 54_z10LMS (e.g. Strong (2010), arXiv:1101.1381)



e.g. Ackermann et al. (2010), Phys. Rev. D 82



Fermi range (J.M. Casandjian talk)

Fermi sources

Isotropic/Extragalactic

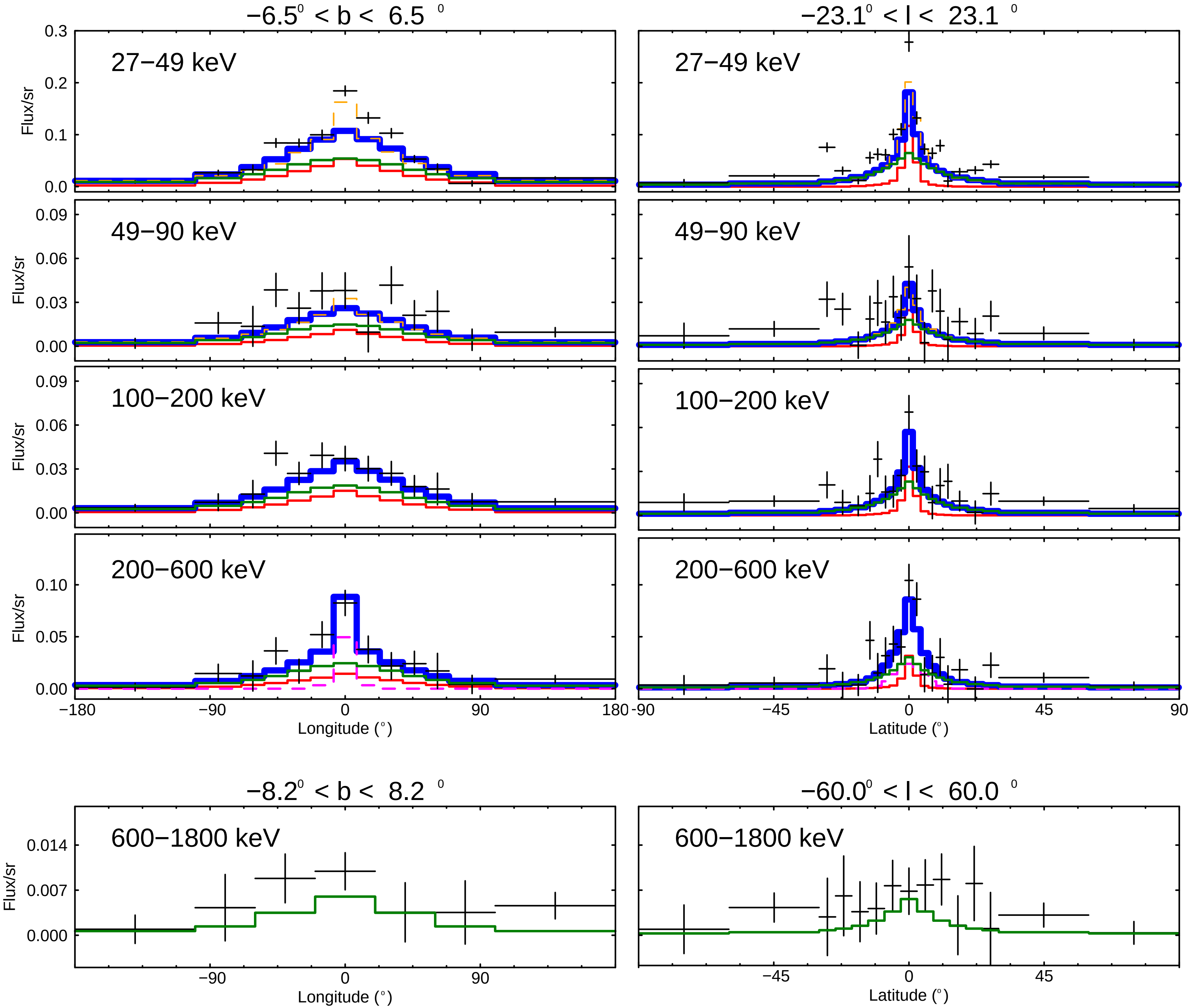
Total diffuse components :

Π^0

Bremsstrahlung

Inverse Compton on interstellar radiation field (optical, IR and CMB) from primary electrons, secondary e+/e-

Diffuse hard X-ray/γ ray emission spatial distribution



2D Fit |l| < 180°, |b| < 90°

❶ IC - GALPROP
= interstellar particle interaction

❷ NIR 4.9μ IR map
(interstellar extinction effects removed)
= stellar emission

❸ Dashed: Positron annihilation (bulge)

Sum: ❶ + ❷ + ❸

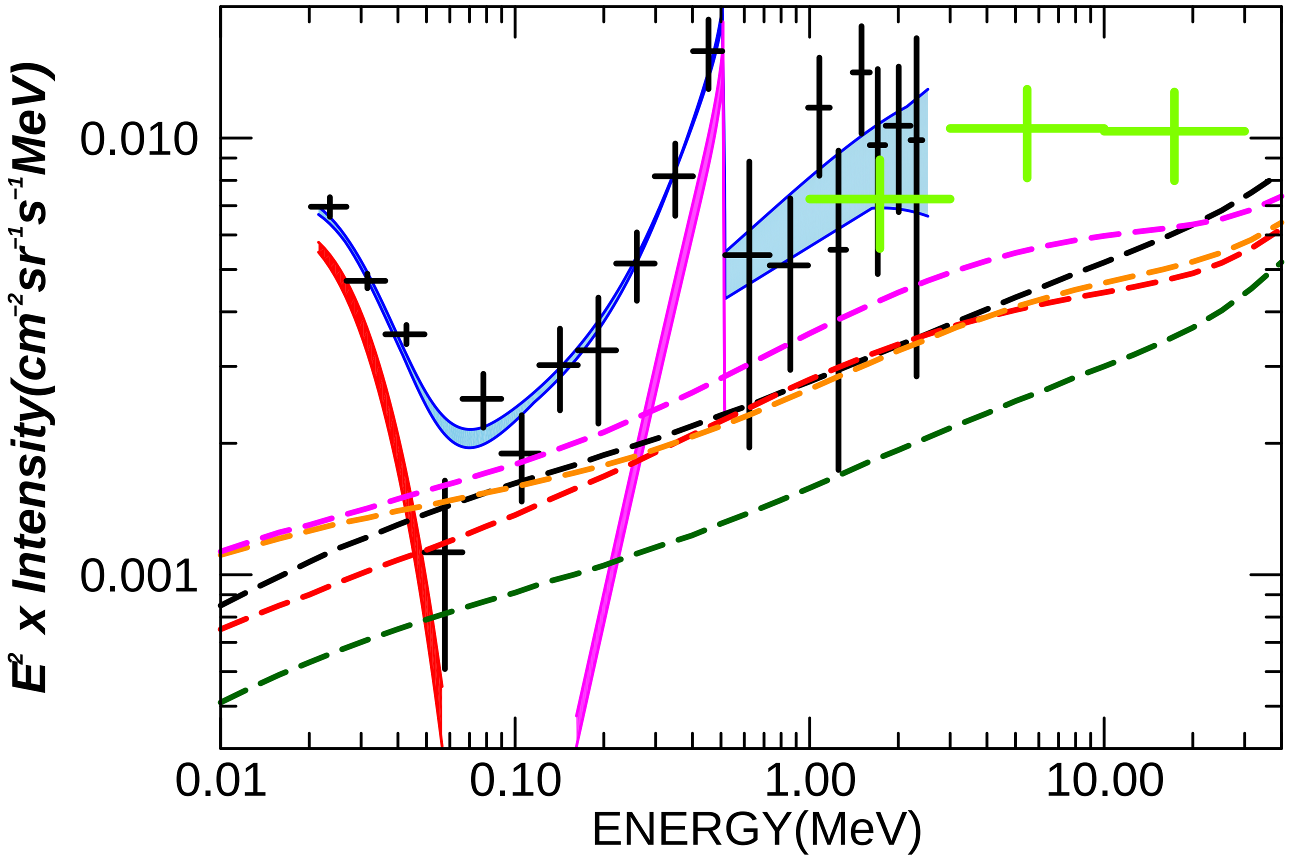
Sum (E < 50 keV) :
❶ + NIR 4.9μ map + ❸

GALPROP IC map:

Primary electron x 2

➔MORE CONSISTENT with SPI

Increasing the hard X-ray/soft γ-ray diffuse continuum emission



<u>|l| < 30° and |b| < 15 °</u>

+ COMPTEL

+ SPI

Low energy "unresolved" sources population

Annihilation radiation spectrum

Blue shaded area : uncertainties on spectral modelling

<u>GALPROP Inverse Compton models</u> (dashed lines)

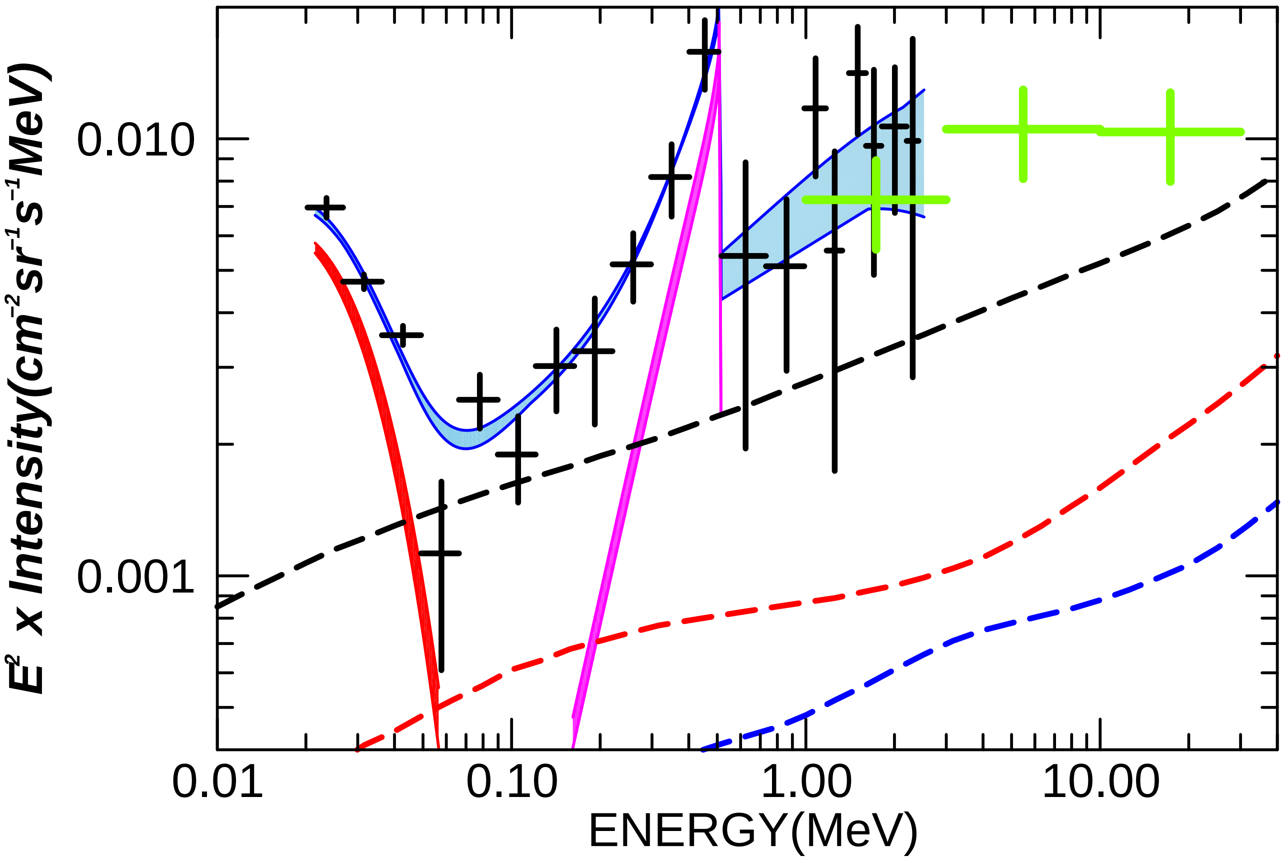
- Primary electron spectrum based on Fermi
- **Primary electron spectrum increased by a factor 2**

Or

- Increased halo height from 4 kpc to 10 kpc
- Increased ISRF in the Galactic bulge (x 10)
- Increased halo height from 4 kpc to 10 kpc and ISRF in the bulge (x 10)

More SPI emission

Electron low- energy spectrum and SPI data



|l| < 30° and |b| < 15 °

+ COMPTEL
+ SPI

Primary electron spectrum :
- increased by a factor 2
- cutoff below 5 GeV
- cutoff below 1 GeV

⟹ Shows that SPI gamma-rays are sensitive to electrons below 1 GeV
probes range which other methods cannot

SUMMARY

20 keV- 2.5 MeV DIFFUSE EMISSION, SPECTRUM AND SPATIAL MORPHOLOGY

►SPI data confirm COMPTEL measurements around the MeV

GALPROP DIFFUSE EMISSION MODELING

►SPI : PROBE of cosmic-rays electrons and positrons
►SPI gamma-rays are sensitive to electrons below 1 GeV

INTEGRAL/SPI CONSTRAINTS

- Electron spectrum
- Halo height
- Interstellar radiation field in bulge

Upper limits on “Fermi bubbles”

PERSPECTIVES

►INTEGRAL mission extension to 2014 would give 12 years of data
Future improvements in data reduction techniques and models

►SPI + FERMI constraints added to those from radio to γ-rays
Use all types of data in a self-consistent way to test models of cosmic propagation

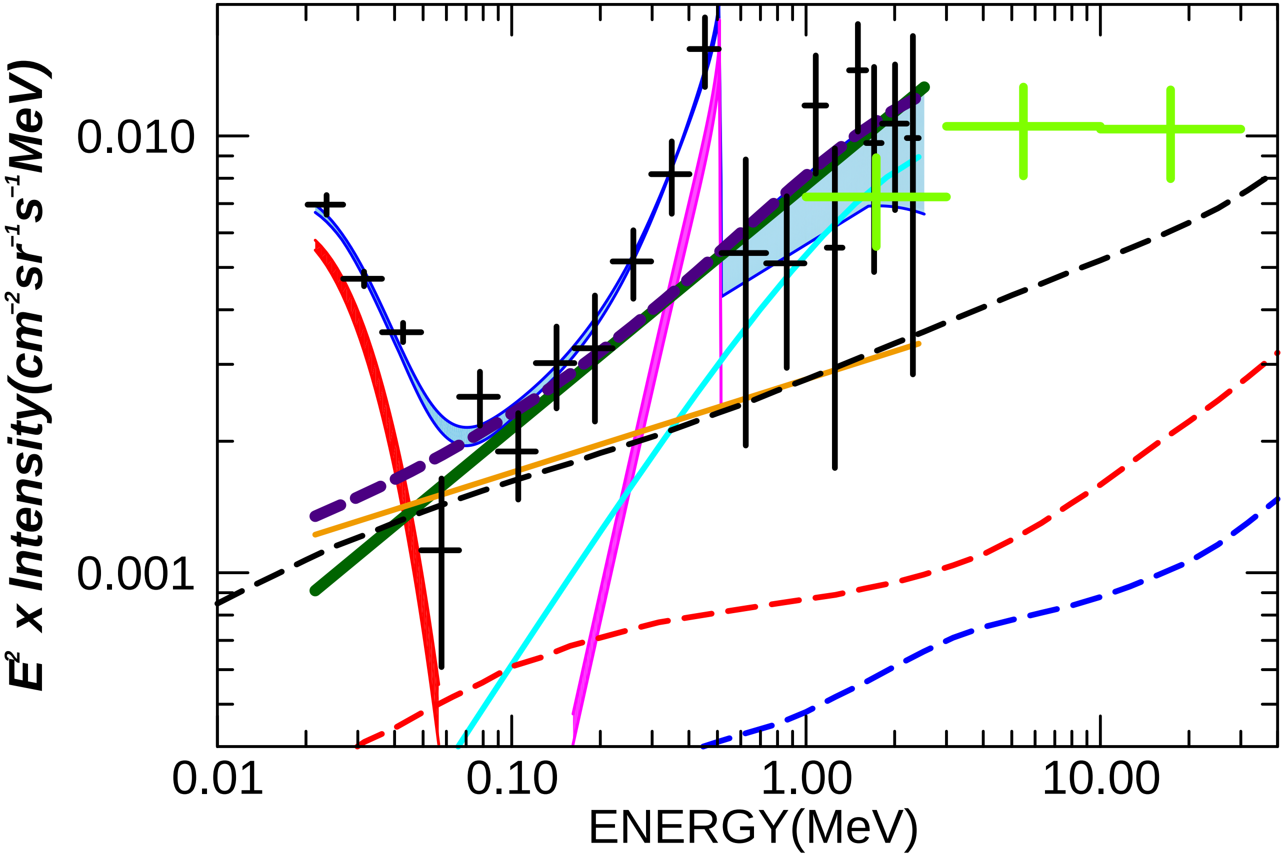
FOREGROUND EXTINCTION IR MAP

The map of the Galaxy in the near infrared spectral band was obtained using data of COBE/DIRBE observations (zodi-subtracted mission average map provided by the LAMBDA archive of the Goddard Space Flight Center, http://lambda.gsfc.nasa.gov). To reduce the influence of the interstellar reddening we considered DIRBE spectral band 4.9μ. We applied first-order corrections to the NIR map of the Galaxy obtained by COBE/DIRBE. We assumed that the intrinsic NIR color temperature (i.e., the ratio of intrinsic surface brightnesses $I_{1.2\mu}$ and $I_{4.9\mu}$) of the Galactic disk and the Galactic bulge/bar is uniform and its true value can be derived at high Galactic latitudes where the interstellar reddening is negligible. Then the foreground extinction map may be expressed as:

$$A_{4.9\,\mu\mathrm{m}} = \frac{-2.5}{A_{1.2\,\mu\mathrm{m}}/A_{4.9\,\mu\mathrm{m}} - 1}\left[\ln\left(\frac{I_{1.2\,\mu\mathrm{m}}}{I_{4.9\,\mu\mathrm{m}}}\right) - \ln\left(\frac{I^0_{1.2\,\mu\mathrm{m}}}{I^0_{4.9\,\mu\mathrm{m}}}\right)\right].$$

~ Here the *A* values are the reddening coefficients at different wavelengths. We have used the interstellar reddening values from works of Lutz et al. (1996) and Indebetouw et al. (2005). The employed correction of course removed only main effects of interstellar extinction on the COBE/DIRBE map, therefore we do not expect that the obtained COBE/DIRBE map and profiles have accuracy higher than ~10% .

Electron low- energy spectrum and SPI data



|l| < 30° and |b| < 15°

+ COMPTEL

+ SPI

Orange : Fitted Inverse Compton component intensity

Cyan : Excess to Inverse Compton

Primary electron spectrum :

- increased by a factor 2
- cutoff below 5 GeV
- cutoff below 1 GeV

⟹ Shows that SPI gamma-rays are sensitive to electrons below 1 GeV : probes range which other methods cannot

Diffuse X-rays/γ-rays from inner Galaxy

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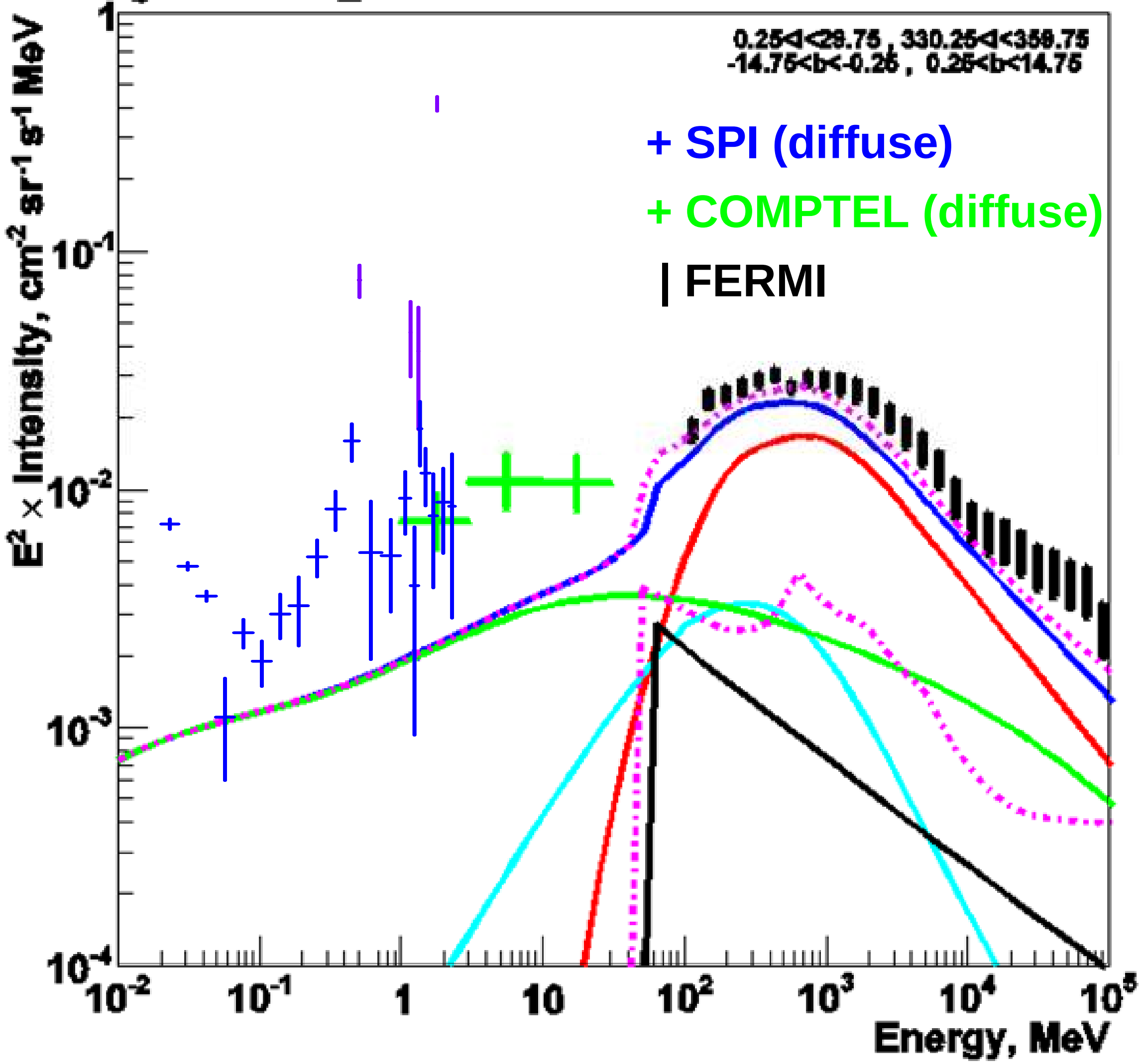
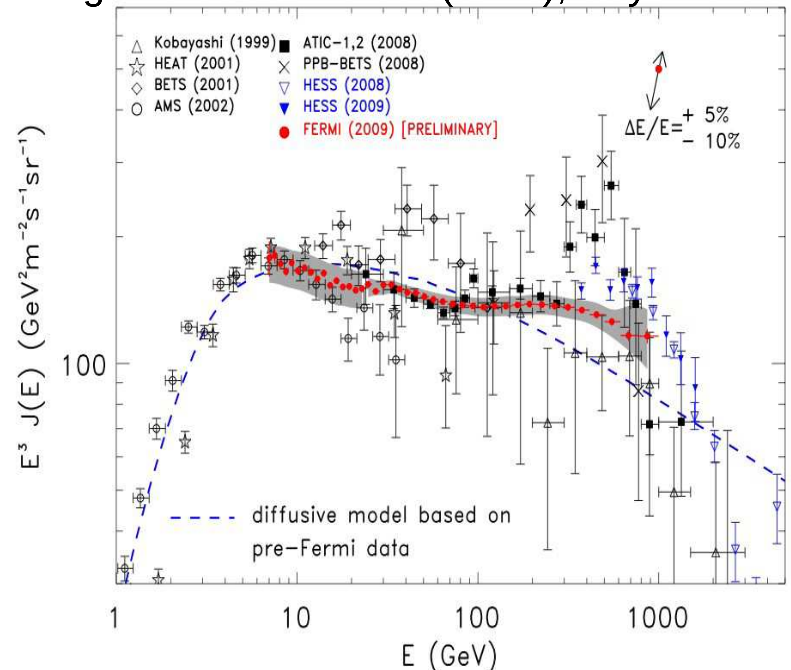
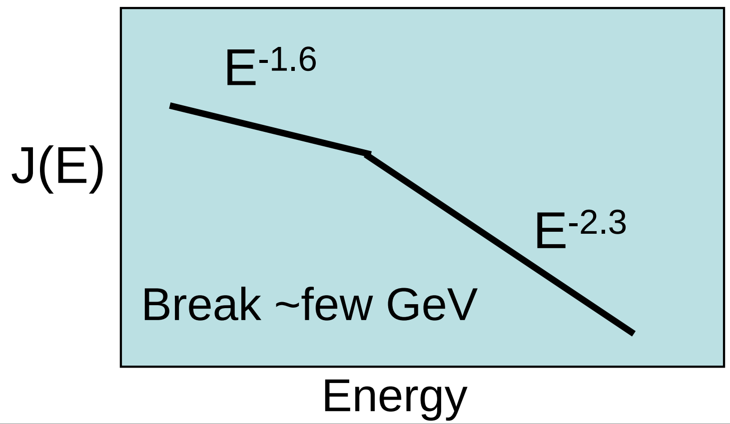


e.g. Ackermann et al. (2010), Phys. Rev. D 82



GALPROP injected electrons



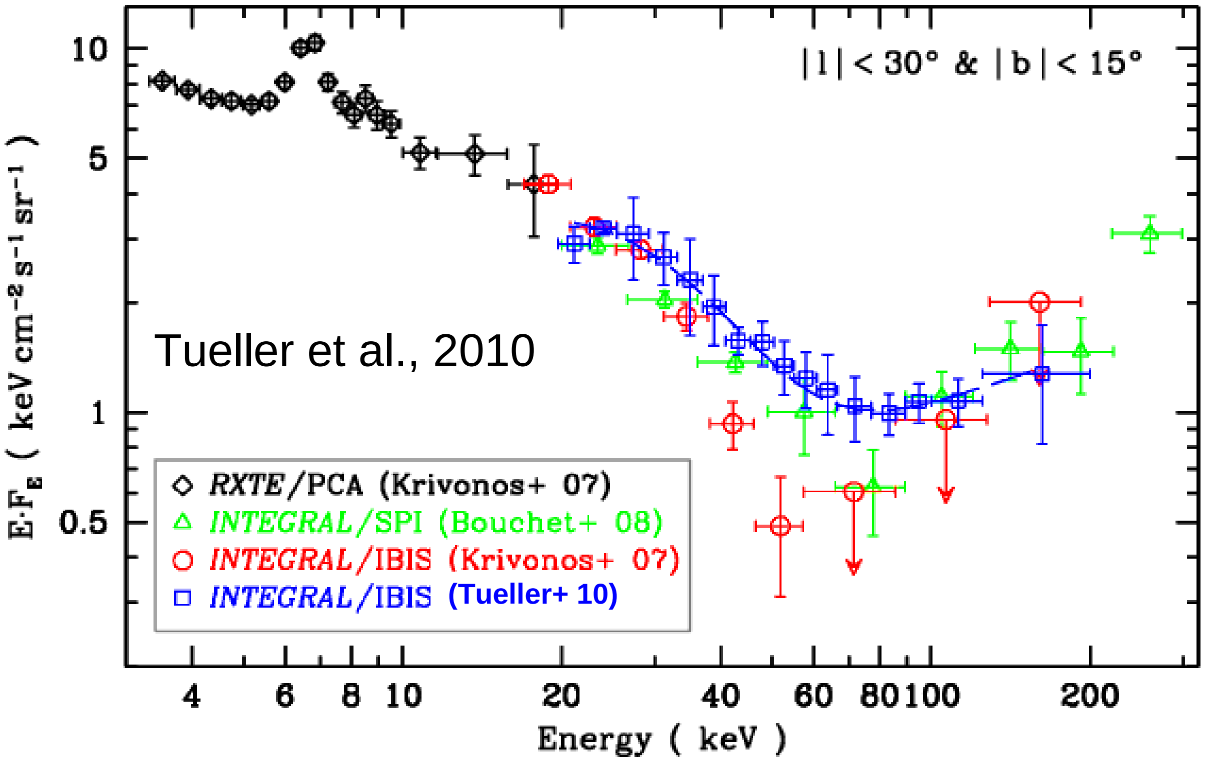
Total diffuse = Π_0 + Bremsstrahlung + Inverse Compton on interstellar radiation field (optical, IR and CMB) from primary electrons, secondary electrons + positrons.

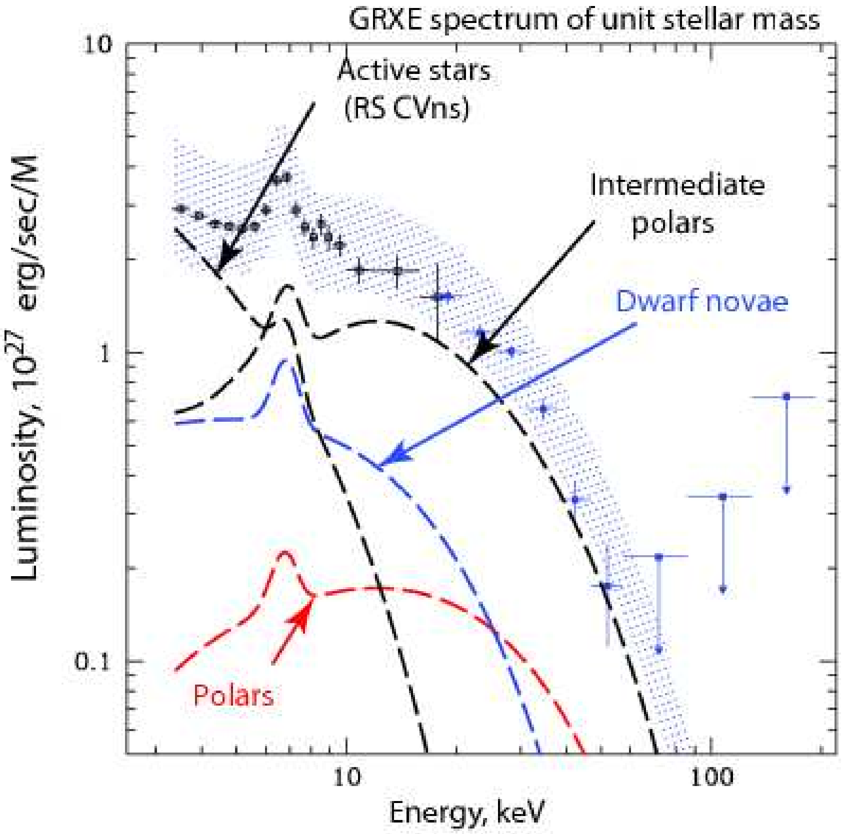
Magenta : Fermi sources – Black : Isotropic/Extragalactic

GRXE hard X-ray measurements with INTEGRAL

INTEGRAL/IBIS

A population of sources composed of CVs may explain a large fraction of the diffuse emission at E < 100 keV (Krivonos et al., 2007, Revnivtsev et al., 2007)





Revnivtsev et al., 2007

GRXE MAIN CHARACTERISTICS

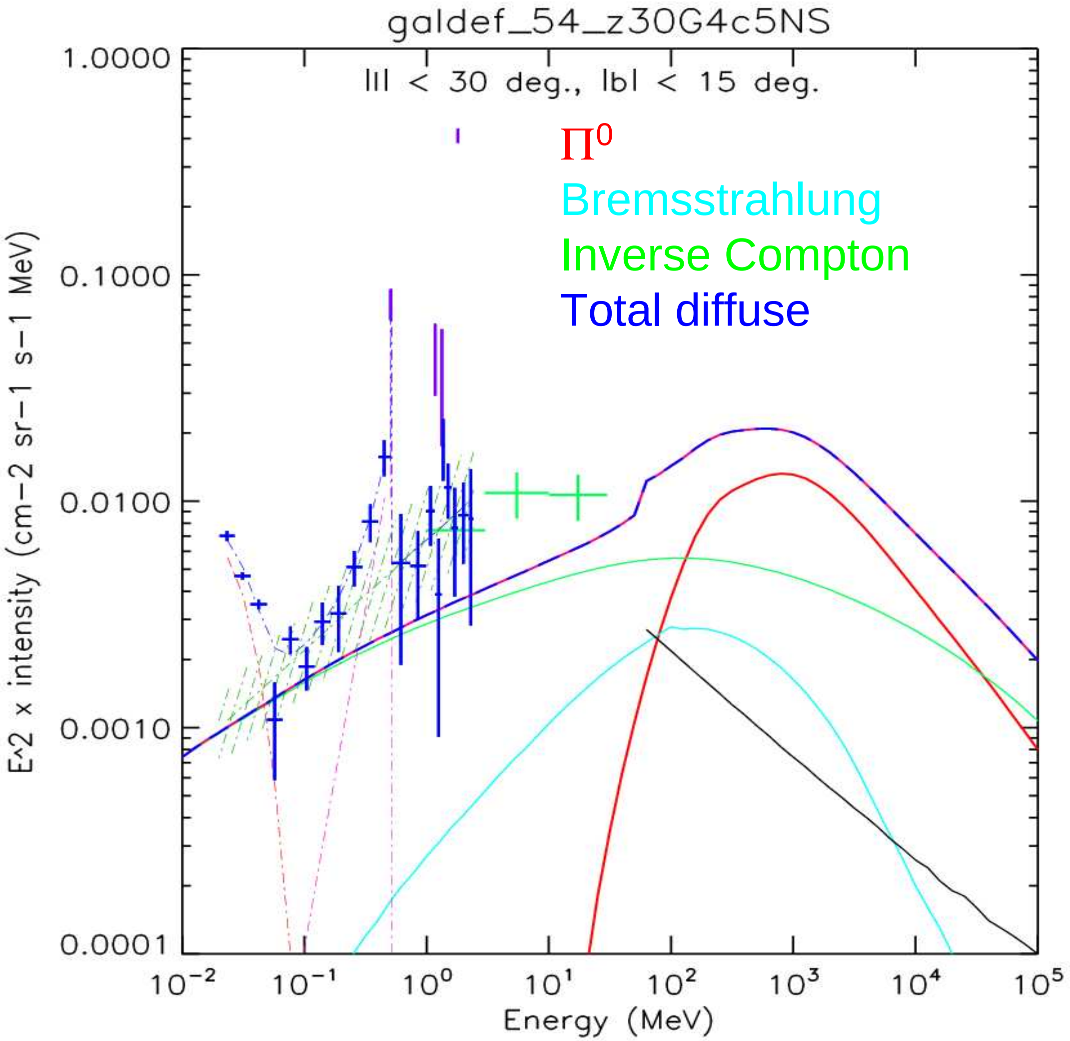
Spatial distribution ~ NIR/DIRBE 3.5 - 4.9 μ

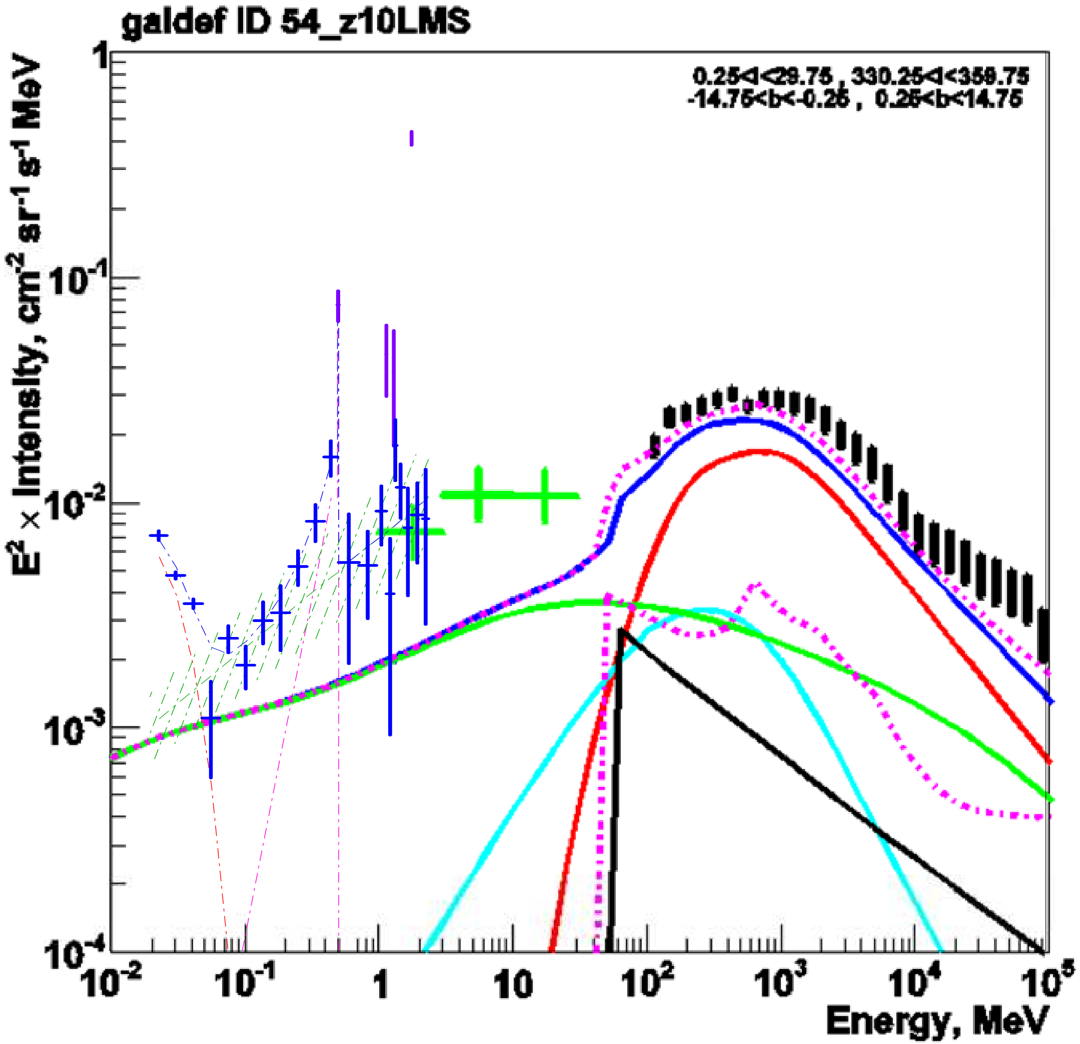
Spectral cutoff at 30-50 keV

L~ 4-6 x 10^{37} erg.s^{-1}

Diffuse X-rays/γ-rays from inner Galaxy

Inverse Compton from primary electrons, secondary electrons + positrons

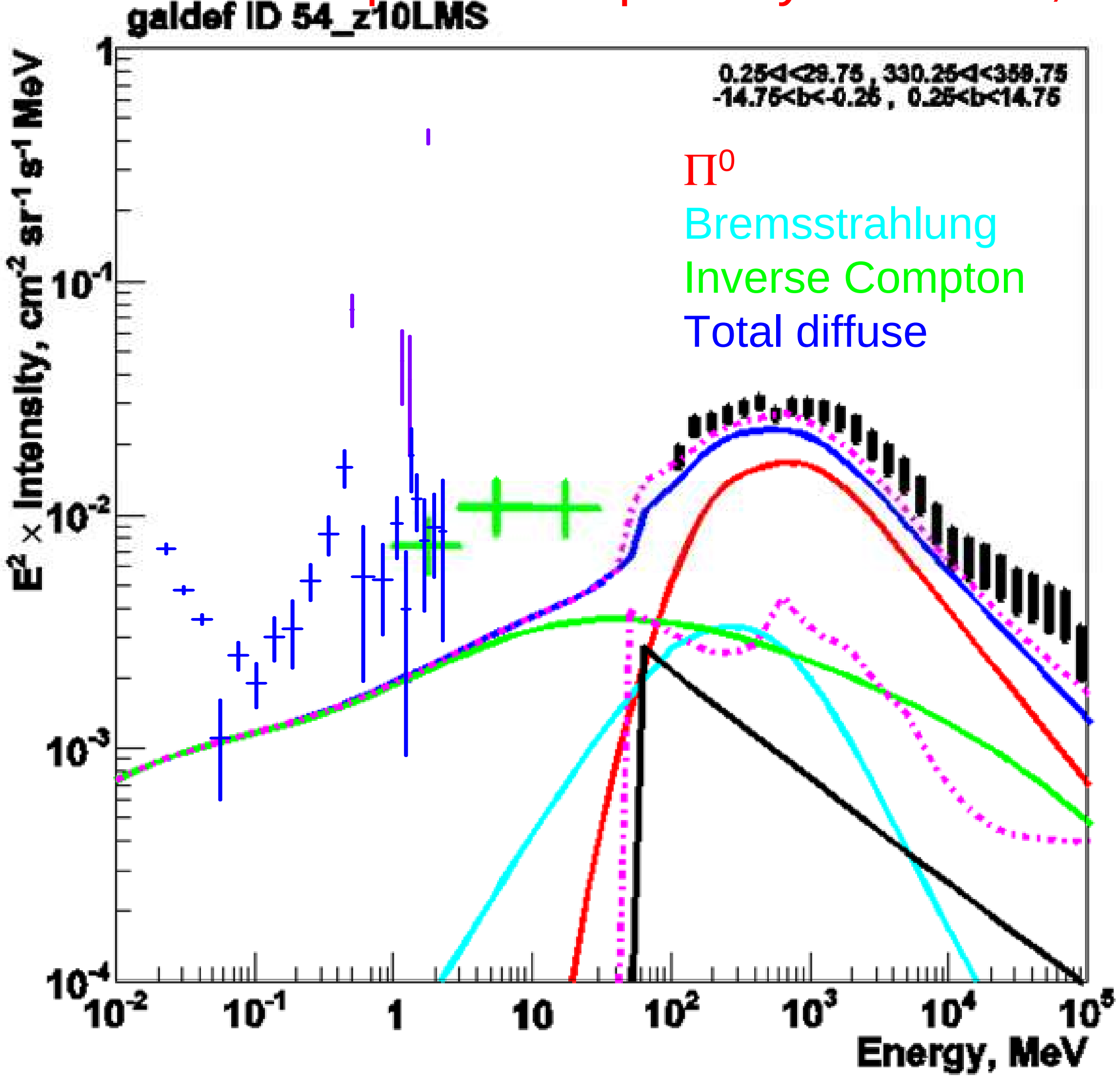




Blue crosses=SPI, Green crosses=COMPTEL, vertical bars=FERMI, Dashed green area : SPI power law continuum measured by INTEGRAL/SPI (Bouchet et al., 2008, Porter et al., 2008, Bouchet et al., 2010, in preparation)

Diffuse X-rays/γ-rays from inner Galaxy

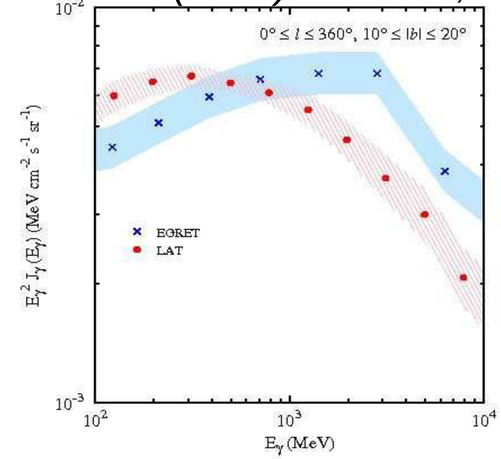
Inverse Compton from primary electrons, secondary electrons + positrons



Blue crosses:=SPI, Green crosses=COMPTEL, vertical bars=FERMI

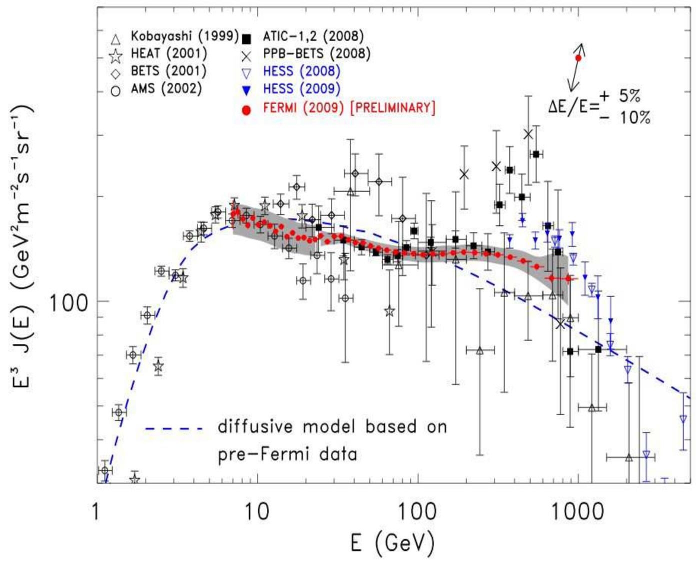
Continuum measured by INTEGRAL/SPI (Bouchet et al., 2008, Porter et al., 2008, Bouchet et al., 2011, in preparation)

Abdo et al (2009) PRL 103, .251101



Fermi does *not* confirm EGRET GeV excess

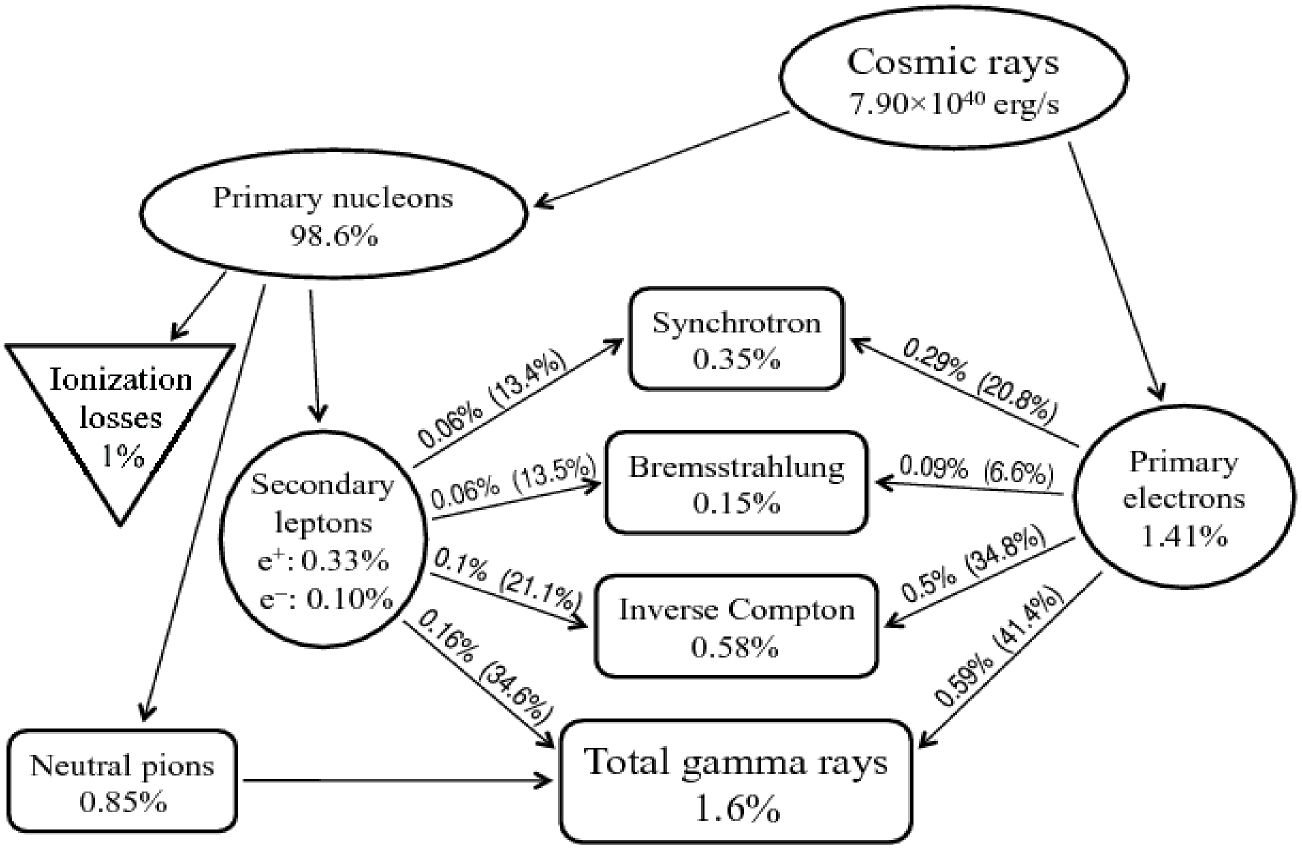
A. Strong, Fermi-LAT, Cospar 2010



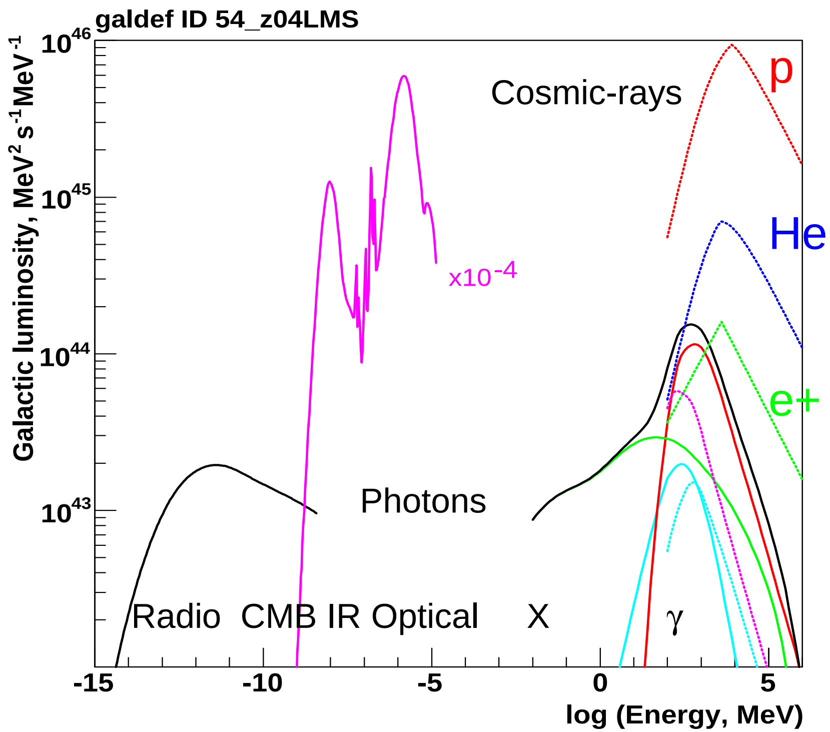
New electron spectrum measurement

GALPROP code
Cosmic-ray luminosity and energy budget of the Milky-way

➔ Use all types of data in a self-consistent way to test models of cosmic propagation



Strong et al., 2010, ApJL, 2010
arXiv1008.4330S



Global CR-induced luminosity spectra of the MW.
Line styles: ISRF, including optical and infrared *scaled by factor* 10^{-4} (magenta solid) and components. Cosmic rays (dotted lines), protons (red), helium (blue), primary electrons (green), secondary electrons (cyan), secondary positrons (magenta); CR-induced diffuse emissions (solid lines), IC (green), bremsstrahlung (cyan), 0-decay (red), synchrotron (black, left side of figure), total (black, right side of figure).