Cosmic rays traced by interstellar emission at Fermi-LAT energies and radio frequencies

E. Orlando (Stanford University/KIPAC), A. Strong, I.V. Moskalenko, S. Digel, G. Johannesson
on behalf of the Fermi Large Area Telescope Collaboration

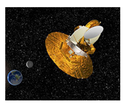
Abstract

Cosmic rays propagate in the Milky Way and interact with the interstellar medium and the magnetic field. This produces diffuse emission in gamma rays and radio. Observations of this diffuse emission and comparison with model predictions are powerful tools to understand the distribution and propagation of cosmic rays. However only a multiwavelength approach can remove degeneracy between different models. Our approach is to look at the two energy domains in a joint analysis of gamma-ray and radio data.
We present Fermi-LAT Pass 8 data extended to lower energies than previously analyzed, thanks to the improved event reconstruction, and compare them with models and radio-synchrotron observations.

Data

Fermi-LAT with Pass 8:

- **Improved event reconstraction** *(see Bruel's talk)*
- **Extended to lower energies (10-100 MeV)**
- **Reduced systematic errors (<5%)**

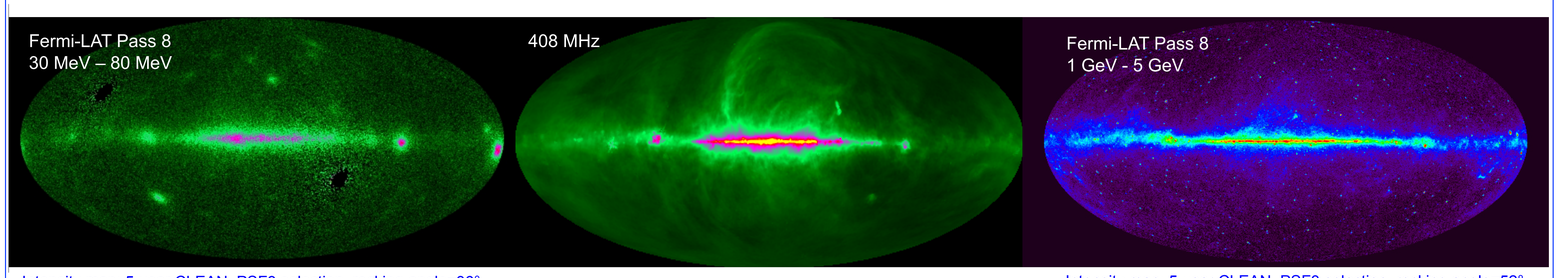


WMAP:
- 9-year data
- Improved component separation technique

Radio Surveys:
- Collection of ground based radio surveys
- 408 MHz (Haslam et al.)

Cosmic-ray (CR) measurements

Multi-wavelength comparison



Intensity map: 5-year CLEAN_PSF3 selection, rocking angle=36°, zenith angle=60°, Sun and Moon removed. Linear scale.

≤ 80 MeV diffuse interstellar emission is mostly of leptonic origin. Electron and positron CR interact with gas via bremsstrahlung and with the interstellar radiation field via inverse Compton (IC) producing gamma rays.

Temperature map, Haslam et al.. Linear scale

At 408MHz diffuse emission is mostly of leptonic origin. The same electron and positron CR that generate gamma rays interact with magnetic fields (B-fields) producing synchrotron radiation observed in radio.

Intensity map: 5-year CLEAN_PSF3 selection, rocking angle=52°, zenith angle=90°. Logarithmic scale

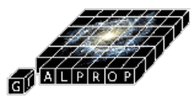
At few GeV diffuse interstellar emission is mostly of hadronic origin. Protons and heavier nuclei CR interact with gas producing gamma rays via pion decay.

Cosmic rays modeling

GALPROP solves the transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species and predict diffuse emissions from radio to gamma rays.

Goal : use all types of data in self-consistent way

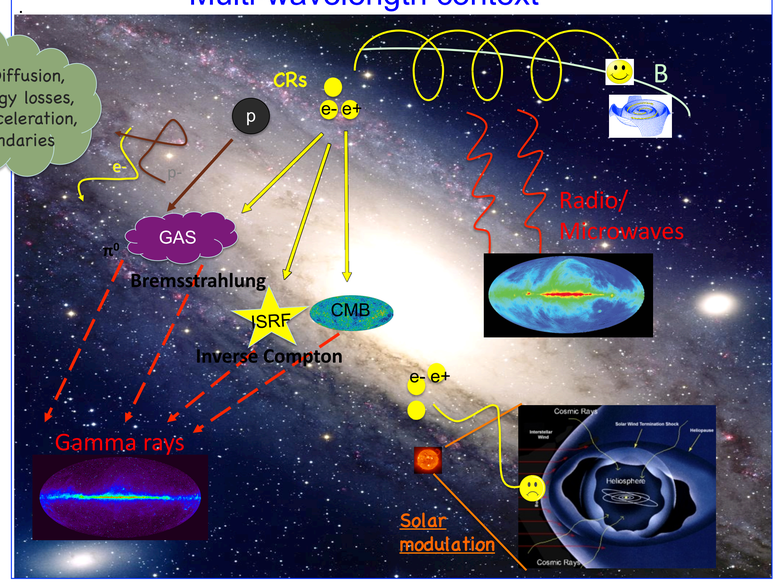
http://*galprop.stanford.edu*



THE TEAM:
I. Moskalenko and A. Strong (original developers),
S. Digel, G. Johannesson, E. Orlando, T. Porter, A. Vladimirov

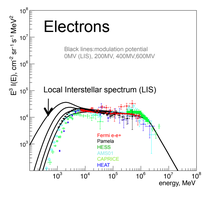
See also Johannesson's talk, this conference, on 3D source distribution implementation and Orlando's poster, this conference, for the 3D magnetic fields and synchrotron implementation.

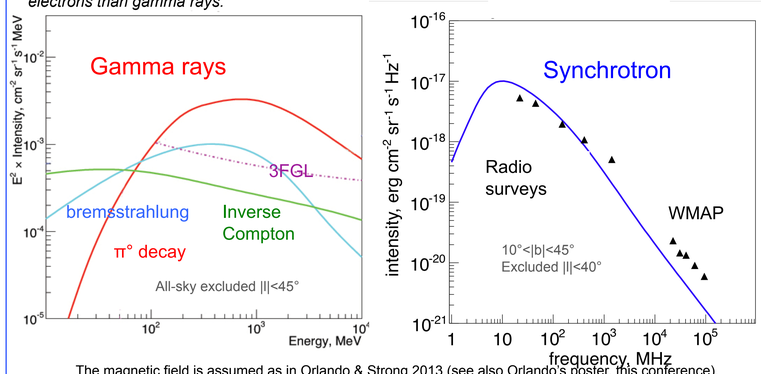
Multi-wavelength context



Example of existing models **with no** constraints from synchrotron

Low-energy electrons are affected by solar modulation, making the knowledge of the local interstellar spectrum (LIS) and prediction of gamma rays more uncertain. Moreover electron spectrum may vary in the Galaxy and both IC and synchrotron are tracing the same spectrum averaged over the line of sight. Synchrotron is more sensitive to those electrons than gamma rays.



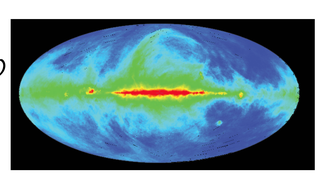


The magnetic field is assumed as in Orlando & Strong 2013 (see also Orlando's poster, this conference).
Interstellar radiation field and gas distribution are asumed as in Ackermann et al. 2012

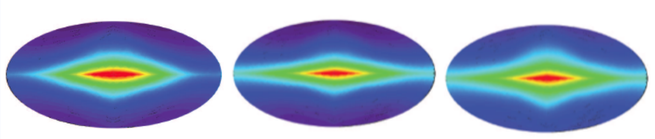
Effect on synchrotron:

CR source distribution and halo size

408 MHz (Haslam et al.)



All these models assume the same magnetic fields. The magnetic field is assumed as in Orlando & Strong 2013 (see also poster, this conference). Temperature maps are in logarithmic scale.



Lorimer 2006 — Strong 2010 — Z=4 kpc — Z=10 kpc

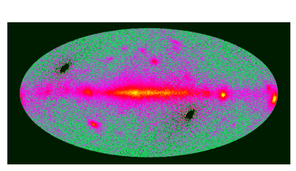
Different CR source distribution

Different propagation halo size

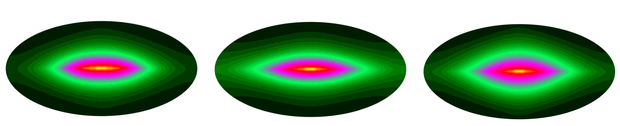
Effect on inverse Compton:

CR source distribution and halo size

Fermi LAT Pass 8 30-80 MeV



At <80MeV the diffuse inverse Compton component is more relevant than at higher energies. However gas and isotrpopic component also may be important. Solar, lunar and Earth limb emission were removed. Intensity maps are in logarithmic scale.



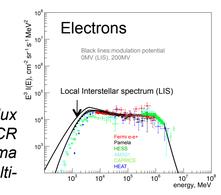
Lorimer 2006 — Strong 2010 — Z=4 kpc — Z=10 kpc

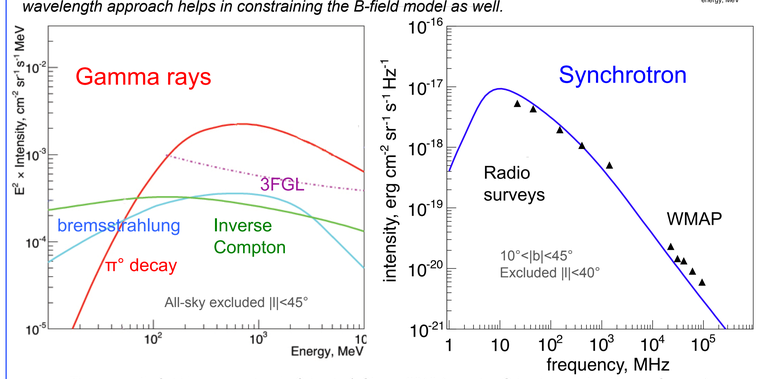
Different CR source distribution

Different propagation halo size

Example of existing models **with** constraints from synchrotron

Synchrotron constrains the spectrum of low-energy electrons. Their flux should be lower than assumed above, but still in agreement with CR measurements. This affects the estimated leptonic components of gamma rays. Moreover, the B-field is not very well known. Hence, our multi-wavelength approach helps in constraining the B-field model as well.





The magnetic field is assumed as in Orlando & Strong 2013 (see also Orlando's poster, this conference).
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REFERENCES: Ackermann, M., Ajello, M., Atwood, W. B., et al. 2012, ApJ, 750, 3
Lorimer, D. R., Faulkner, A. J., Lyne, A. G., et al. 2006,MNRAS, 372, 777
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Strong, A. W. et al. 2010,ApJL, 722, L58

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eorlando@stanford.edu