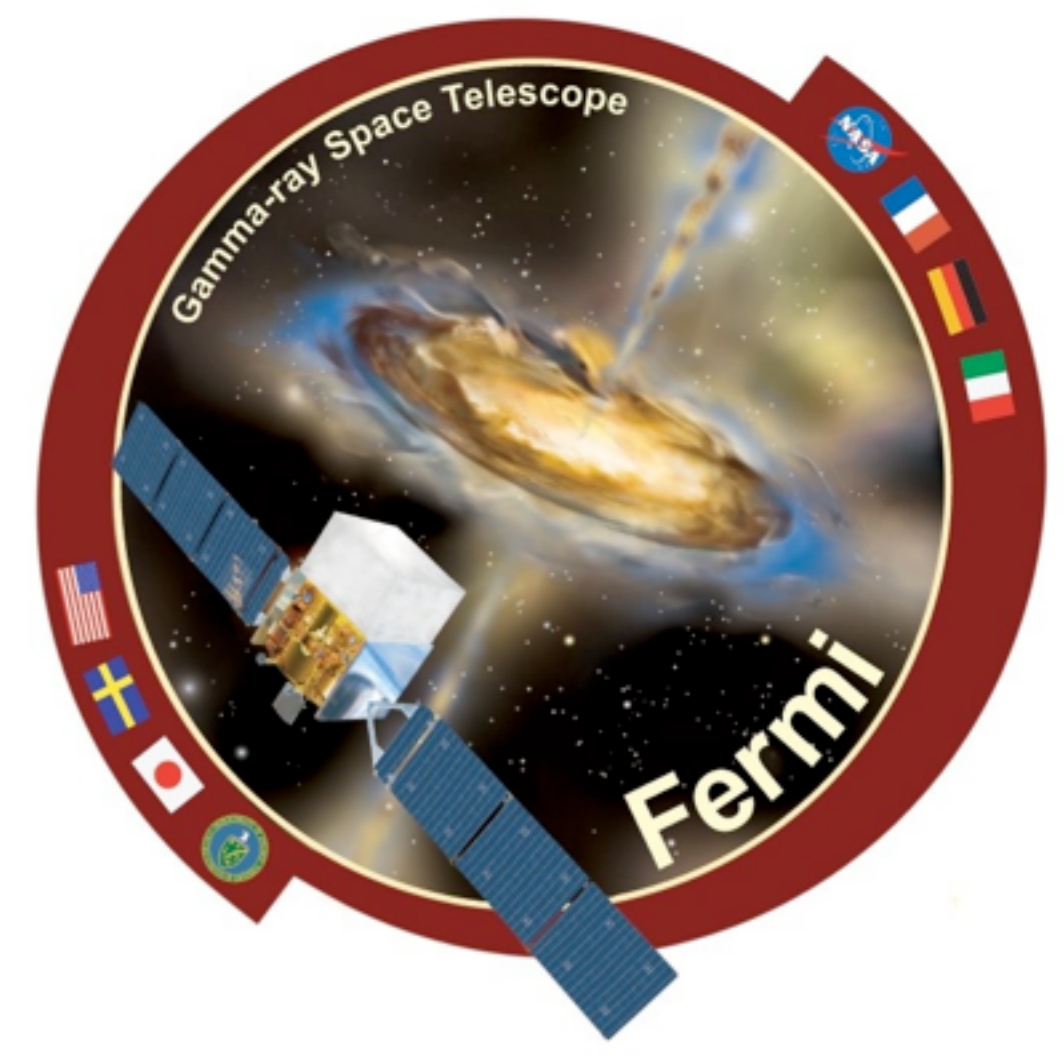# High Energy γ-Ray Emission from the Loop I region

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**We observe an excess of γ rays in the direction of Loop I which is probably due to the inverse Compton emission of hard electrons also seen in the polarized WMAP synchrotron map.**

## Abstract

Loop I is a nearby giant radio loop spanning over 100 degrees and centered on the Sco-Cen OB association. It may correspond to a superbubble formed by the joint action of stellar winds and supernova remnants. ROSAT observations revealed that the region is filled with a hot gas possibly reheated by successive supernova explosions. The brightest rim of Loop I, called the North Polar Spur (NPS), extends to the north along 30 degrees in longitude, at a distance of about 100 pc from the Sun. Early searches for high-energy γ rays associated with electrons or protons accelerated by Loop I were performed with SAS-II, COSB and EGRET. But a detector with better performance and higher statistics is required to distinguish the faint signal from the NPS from broad structures in the Galactic interstellar emission, such as the inverse Compton emission from cosmic-ray electrons scattering the interstellar radiation field. We modelled the γ-ray emission of the Galaxy and compared it to the Fermi-LAT photons detected above 300 MeV. We observe an excess of photons in the direction of Loop I. This excess exhibit arc-shaped structures similar to those seen in the polarized synchrotron emission; the correlation suggests an inverse Compton origin of the γ rays from hard electrons in Loop I.

## Loop I in radio

The local interstellar medium is known to contain several bubbles or large supernova shells like the Local Bubble within which the Solar System resides. Six major Galactic loops, obtained by joining radio spurs into circles, were discovered in radio-continuum surveys. Loop I, discovered by Large, Quigley & Haslam in 1962, is the most prominent one. It is a nearby giant radio loop spanning over 100 degrees and centered on the Sco-Cen OB association. The brightest feature of Loop I, called the North Polar Spur (NPS), is located in the northern hemisphere at a longitude around 30 degrees and is at a distance of approximately 100 pc from the Sun. The spur is best seen in the 408 MHz survey of Haslam et al, 1981, in addition to the synchrotron emission along the Milky Way that arises from cosmic-ray electrons interacting with the Galactic magnetic field. From the synchrotron index map from Miville-Deschênes et al. (2008), it appears that the Haslam map is dominated by soft electrons toward the inner plane, unlike synchrotron maps measured at higher frequency like the WMAP polarized emission at 23 GHz from Page et al. (2007). Since only synchrotron emission is polarized at this frequency, this map is clean of dust and free-free contribution, however the variation of the angle between the magnetic field and the line of sight directions depolarizes the signal so the map do does fully represent the total synchrotron intensity. This effect is corrected in the synchrotron emission map at 23 GHz of Miville-Deschênes et al. (2008).


408MHz, Haslam *et al.*, 1981


Synchrotron spectral index between 408MHz and 23GHz Miville-Deschênes *et al.*, 2008


WMAP polarized emission at 23GHz, Page *et al.*, 2007


Synchrotron emission at 23GHz Miville-Deschênes *et al.*, 2008
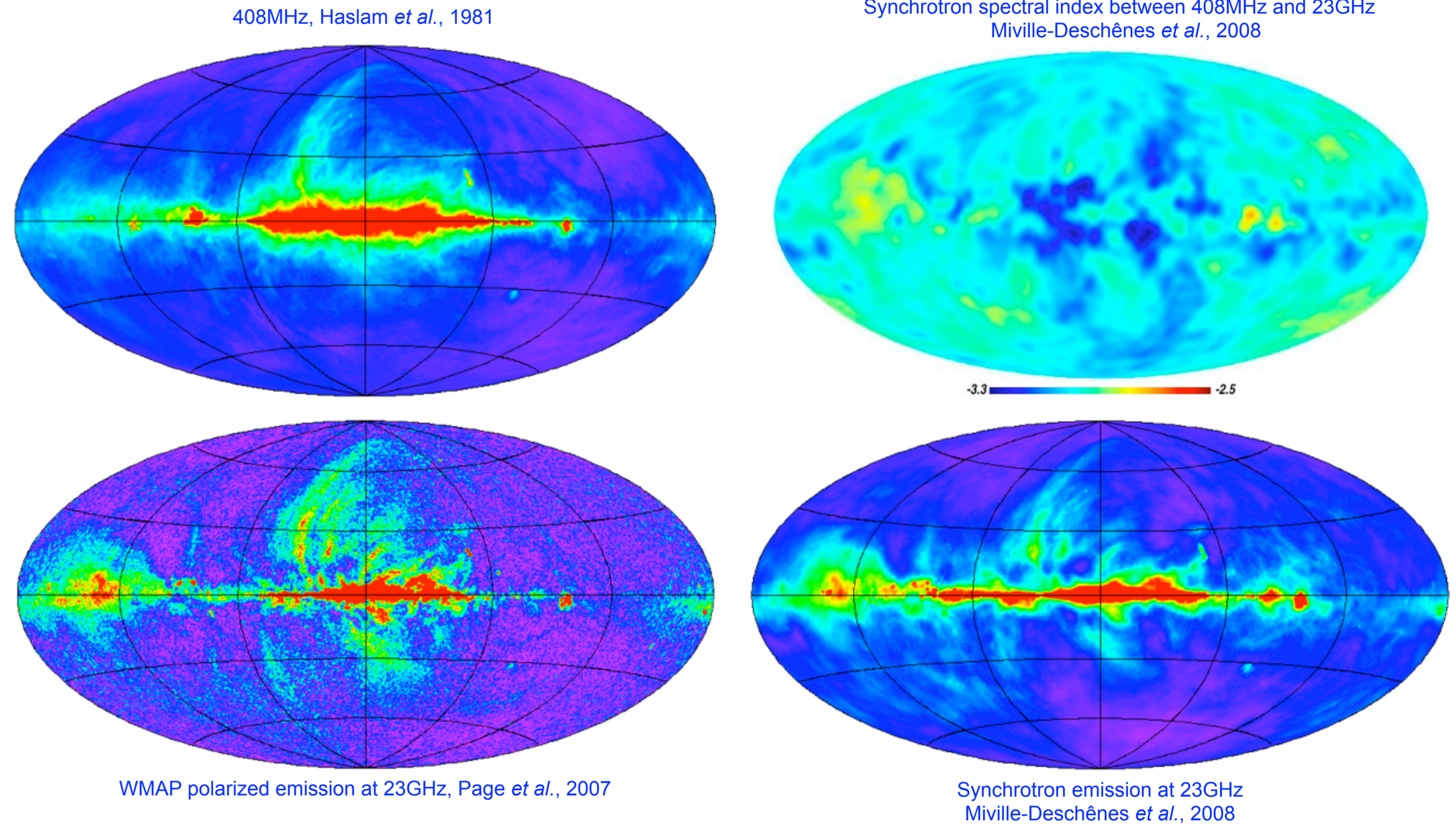
## Earlier searches for γ rays from Loop I

The search for high-energy γ rays from Loop I dates back to SAS II. In the letter to Nature called "Acceleration of cosmic rays in the Loop I 'supernova remnant' ?", Bhat *et al.* (1985) claim to have detected an excess of intensity toward Loop I. More claims of detected emission were published latter with COS B and EGRET photons. But distinguishing between the signal from Loop I and broad structures in the Galactic interstellar emission, like the inverse Compton emission from cosmic-ray electrons scattering the interstellar radiation field requires a precise Galactic diffuse emission model, and the systematic uncertainties of the models used at that time were probably much larger than the number of claimed photons. With an improved diffuse emission model, Grenier, Casandjian and Terrier (2005) have detected a significant correlation between the EGRET photons and the 408 MHz synchrotron map toward Loop I.
If powered by supernovae, Loop I is at a very advanced stage of radiative expansion. But the case of Loop I is complex. An age of around 1 Myr was inferred from the low expansion velocity of the neutral gas surrounding the loop. However, since radio and X-ray emission are still visible, it is probable that Loop I has recently been reheated by one or more supernove. No proton acceleration is expected in this old loop, but the radio data indicate that relativistic electrons are still spiraling around complex magnetic structures.

## Fermi-LAT photons and the Galactic diffuse emission model

In order to observe extended objects with faint intensity, a precise modelling of the emission from the bulk of the Galaxy is required. This emission is produced in the interactions of energetic cosmic-ray electrons and protons with interstellar nucleons and photons. The decay of neutral pions produced in hadron collisions, the inverse Compton scattering of the interstellar radiation field by electrons and their bremsstrahlung emission in the interstellar gas are the main contributors to the Galactic emission. If energetic cosmic rays penetrate uniformly all gas phases, the γ-ray intensity in each direction can be modelled by a linear combination of gas column-densities (obtained from radio and infrared surveys), an inverse Compton intensity map (calculated by GALPROP), and an isotropic intensity that accounts for the very local inverse Compton emission, the extragalactic γ-ray background, and the residual instrumental background. To account for the non-uniform cosmic-ray flux through the Galaxy, the gas column densities are distributed within six galactocentric rings. To obtain the model intensity, the emissivities for each of those components were fitted to Fermi-LAT photons. The data used in this study were obtained in the all-sky survey mode, summing all the valid statistics of the last 14 months. We selected photons from the P6_V3_Diffuse class having a zenith angle less than 105º and an energy above 300 MeV so that we have both large photon counts and good spatial resolution.


Fermi-LAT counts map for E>300MeV with sources removed


diffuse model counts prediction for E>300 MeV

## Results

The upper map to the right shows the difference between the photon counts detected by the Fermi-LAT above 300 MeV and the counts expected from the diffuse emission model above the same energy. We have masked the Galactic plane for |b|<5º. The map below shows the polarized 23 GHz intensity measured by WMAP (Page *et al.*, 2007).

The residual map shows arc-like structures on both sides of the plane that are strongly reminiscent of the synchrotron spurs observed in polarized light by WMAP at 23GHz or in the synchrotron component extracted at 23 GHz by Miville-Deschênes *et al.*. These "arcs" are best seen along the NPS (l ~ 30°) and l ~ 20° up to 50° in latitude, and at l ~ 290° from 30° to 60° in latitude. The southern excess is present, but less clearly related to the synchrotron polarized intensity. The spatial relation between the radio and γ-ray data suggests that synchrotron-emitting hard electrons also produce γ rays by upscattering the local radiation field. A bremsstrahlung origin is less likely because of the hardness of the γ rays and because the excess better coincides with the radio spur than with the dense rim of compressed atomic hydrogen. This study indicates that the largely dominating inverse Compton emission from the Milky Way (as calculated by GALPROP) together with this fainter local excess linked with Loop I can fully account for the Fermi-LAT data. No obvious haze or additional diffuse structure is needed.

The high sensitivity of the LAT together with a precise model for the Galactic emission allowed for the first time the observation of an excess of γ rays related to Loop I. They probably originate from local relativistic electrons, however only a careful study of their spectra and of the spatial correlation with the synchrotron data will confirm the emission origin.
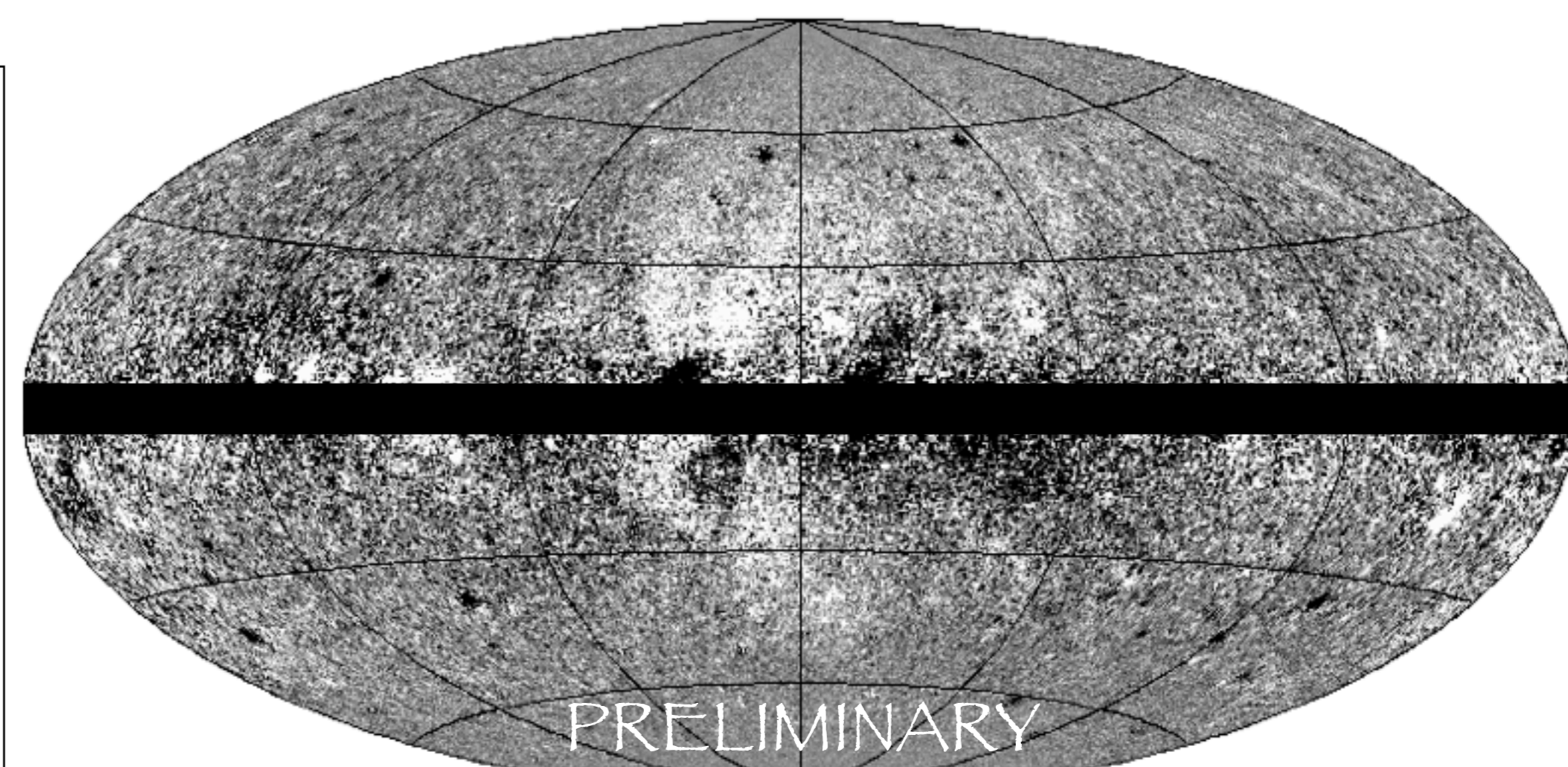

PRELIMINARY
Residual map (data-model) for photons with E>300 MeV
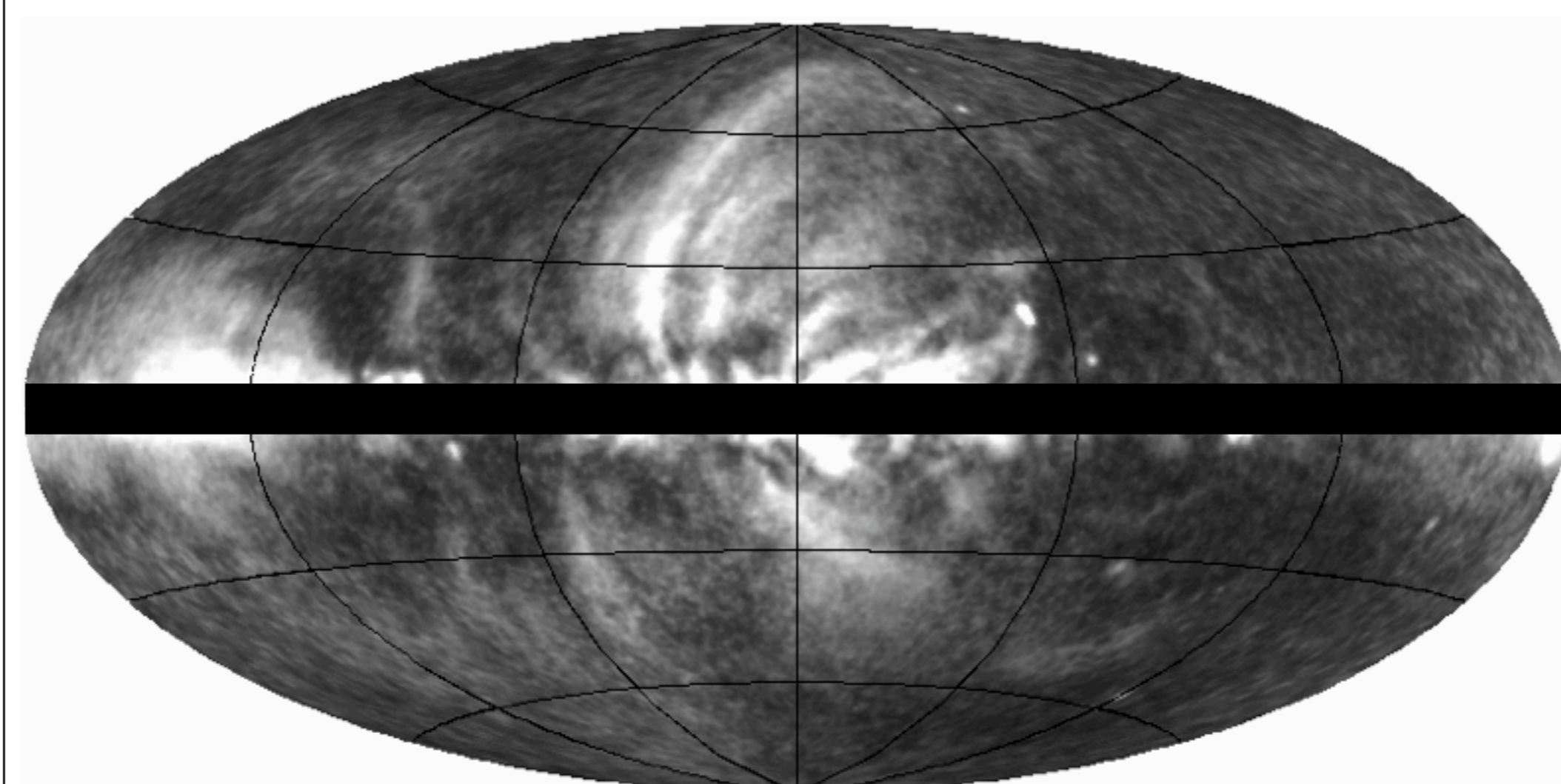

WMAP 23GHz polarized intensity convolved with Fermi-LAT PSF for E>300 MeV

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