SKYMOS: method and results

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1 Introduction

SKYMOS is a skymapping method based on multiple independent observation data. The aim to obtain intensity distributions which are both quantitative and independent of external assumptions. The idea is to preserve the information from each observation and to work in the instrumental system to enable the background to be directly addressed. The dataspace is therefore simply the set of all selected DRX, DRG and DRE datasets produced by SKYDRI in the instrumental system. SKYMOS uses this approach in combination with the maximum entropy imaging method, but the same idea would also be applicable and advantageous to model-fitting.

2 Method

2.1 Response representation

It is assumed that the COMPTEL response for one observation i to an intensity distribution I_γ has the usual form

$$n_i(\chi,\psi,\overline{\varphi}) = g_i(\chi,\psi,\overline{\varphi}) \int\int I_\gamma(\chi',\psi')X_i(\chi',\psi')f(\chi',\psi',\chi,\psi,\overline{\varphi})d\Omega + B_i(\chi,\psi,\overline{\varphi})$$

where n_i the the expected counts in the DRE of the observation, g_i are the geometrical factors (DRG), X_i is the exposure (DRX) and f is the point-spread function (IAQ), Ω is the solid angle. $B_i(\chi,\psi,\overline{\varphi})$ is the instrumental background of the observation. The full dataspace of N observations consists of all the DREs, and the response of all the DRX and DRG.

2.2 Background template

The background is represented as

$$B_i(\chi,\psi,\overline{\varphi}) = B_o(\chi,\psi,\overline{\varphi})b_i(\overline{\varphi})$$

where B_o is a template derived for example from many high-latitude observations, and b_i is the scaling factor for the observation i for each $\overline{\varphi}$. The b_i are treated as free parameters to be determined, so that finally we only use the (χ, ψ)-distribution of the template. The b_i thus include both temporal and $\overline{\varphi}$ variations of the background, and give $n_{\overline{\varphi}}$ parameters per observaion. However for cases where the $\overline{\varphi}$-distribution is known to be stable (for example above 10 MeV) it can optionally be taken from the template, so that only temporal variations considered, with only one parameter per observation. The time-dependence of the background is a by-product of the method which can be compared with other determinations.

Using high latitude observations the template is generated using

$$B_o = \frac{\Sigma n_i(\chi, \psi, \overline{\varphi})}{\Sigma g_i(\chi, \psi, \overline{\varphi})\overline{X_i}}$$

Since the DRE and DRG data are always in the instrument system they are aligned for all observations, so that no interpolation is required.

2.3 Convolution

The convolution is done explicitly using the IAQ datasets which give the PSF as a function of angle between two points on the sky for each $\overline{\varphi}$. The fact that this has to be done by 'brute force' and for every observation separately is the reason for the large compuational requirements of SKYMOS.

2.4 Maximum Entropy application

The MEMSYS5 package is used, with OPUS and TROPUS being defined in the normal way using the response defined above. The background parameters b_i are treated as an extension of the image space and are determined during the iterations along with the image. Although the image and background parameters are thus mixed in the entropy calculation the background parameters are constrained by the data so the entropy plays almost no role in their determination. Further since the entropy formula contains each 'pixel' independently there is no feedback from the background parameters to the image.

The only free parameter required in running MEMSYS5 is then the default level; this mainly affects the rate of convergence to the final intensities, but whose influence should nevertheless be checked. Unlike SKYMEM there is no need to include a special background treatment (and a corresponding approximation) in OPUS and TROPUS (this was introduced in MEMSYS2 specially for COMPTEL by Skilling).

3 Implementation

The method has been implemented on Sun workstations where it produces images based on a few observations in normal running times. However for large number of observations and large (e.g. all-sky) images this is not practical because of the very large CPU requirements. On the other hand the response calculation for each observation is independent of all the others, which lends itself naturally to implementation on a parallel computer. The porting to the T3E at the Rechenzentrum Garching took several months of work but now allows full sky maps based on 240 observations from Cycle 1-6 with 1^o binning to be produced systematically. The parallelizing technique is to assign one PE (processing element) to each observation, and to run SKYMOS simultaneously on all PEs. Upon reaching the convolution part of the calculation each PE computes only the response for its assigned observation; the result is then transmitted to all other PEs so that each obtains the full response as required for the imaging. In this way the 'acceleration factor' is practically equal to the number of PEs. For full-sky images one convolution requires about 5 minutes CPU, and one MEMSYS5 iteration requires about 10 convolutions. This gives about 1 iteration per CPU hour. Intermediate results are stored so that high iterations are reached in repeated standard 6-hour runs. In practice several weeks must be allowed per map to obtain the required processing in the standard queue.

4 Results

Full-sky maps with 1^o binning have been produced in the 1-3, 3-10 and 10-30 MeV ranges. For the 10-30 MeV range the revised TOF selection of Werner Collmar was used, for the others the standard selection. The most recent wide-beam IAQs for E^{-2} were used. The observations used for the background template were those with pointings with $|b| > 60^o$. For 1-3 MeV and 3-10 MeV background $\overline{\varphi}$-distribution was free, for 10-30 MeV it was taken from the template. Iteration was continued until the intensity converged. The final iterations are shown in the skymaps (Fig 1). Since high iterations were used, images smoothed over 3^o and 5^o bins are also shown.

The background as a function of observation is shown in Fig 2. The general increase with time and the reboost features are as expected, with 1-3 MeV showing the largest variation, and 10-30 MeV showing only a very small increase. The values are normalized by time so that the average would be expected to be near 1.0, or slightly less since the high-latitude background includes some sky isotropic component which can better be included in the image intensities as it is not time variable. The average scaling also depends on the distribution of the high-latitude observations along the time-line which can lead also to deviations from unity. The average is indeed near unity for the two low ranges. The variations in $\overline{\varphi}$-distribution are larger in 3-10 MeV than 1-3 MeV, as might be expected from the fluctuations in activation between observations. The average scaling factor is lower for 10-30 MeV; this can be attributed to the fixed $\overline{\varphi}$-distribution combined with the presence of the isotropic component of the real gamma-ray sky in the background template. The time-varying instrumental background has a different signature from this component so that, correctly, only a fraction of the template is finally assigned to the data, the rest being attributed to isotropic sky emission. In the 10-30 MeV range the contribution of the isotropic component is largest so this effect is maximum. However the $\overline{\varphi}$-distributions of the isotropic and instrumental components are sufficiently similar that quite large fluctuations occur in the fitting, as is evident from the figure.

The intensity for regions $|l| < 30^o$,$|b| < 5^o, 10^o, 20^o$ as a function of iteration is shown in Fig 3 (TOF correction not included). It shows that high iterations (50-100) are required to get convergent intensities (note this is a characteristic of MEMSYS5 which converges more slowly than the old MEMSYS2. One reason is presumably the more accurate treatment of Poisson statistics). The intensity is fully saturated except for 10-30 MeV ,$|b| < 20^o$ where a further increase by 10% can be expected.

Latitude and longitude profiles of the maps are shown in Fig 4 (TOF correction included). Latitude profiles are for $|l| < 30^o$ and with 1^o latitude bins. Longitude profiles are for $|b| < 5^o$ and $|b| < 10^o$ with 1^o and 5^o longitude bins.

Note that the absolute offset is by definition arbitrary since the technique is differential; the profiles are plotted as they are generated. (An offset can also be included for example by assuming the polar regions have the intensity of the isotropic background from other studies.) Latitude profiles as function of iteration (Fig 5) show how the contrast increases to saturation while fluctuations build up at high iterations.

The iterations are chosen to saturate the intensities, at the cost of increased fluctuations, which are visible at high latitudes. This gives an estimate of the systematic error on the profiles, which is used as the basis for the plotted error bars. The peaks around b=$\pm 20^o$ attributed to such fluctuations on top of the general profile and are therefor not significant.

Spectra for $|b| < 5^o$,$|b| < 10^o$, and $|b| < 20^o$ are shown in Fig 6. These are derived from the intensities relative to the average $30^o < |b| < 70^o$. For $|b| < 5^o$ the spectra are between a factor 1.5 and 2 higher than in Strong et al. 4th COMPTON Symposium, where the first attempt was made to get intensities from continuum skymaps. The present results are nearer to Hans Bloemen's 4th COMPTON Symposium spectrum based on fitting.

The maps can be used to find point sources, and has the advantage of not requiring external assumptions about the underlying distribution. Point sources show up as intense concentrations well above the surrounding level.

5 Datasets

The FITS datasets of the final maps as well as the iterations can be found at
http://www.gamma.mpe-garching.mpg.de/comptel/collab/aws/aws.html

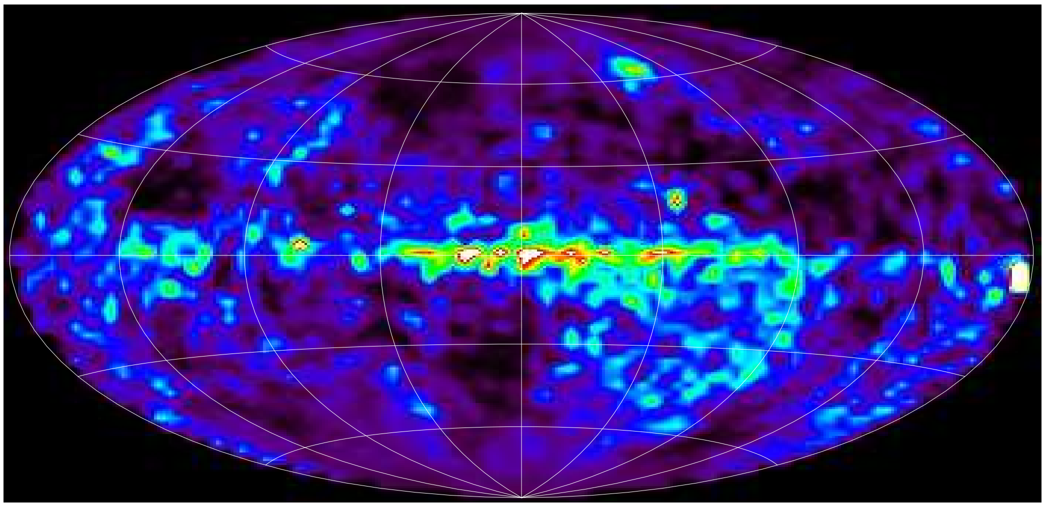
6 INTEGRAL Workshop, Taormina

Suggested content of Taormina paper:

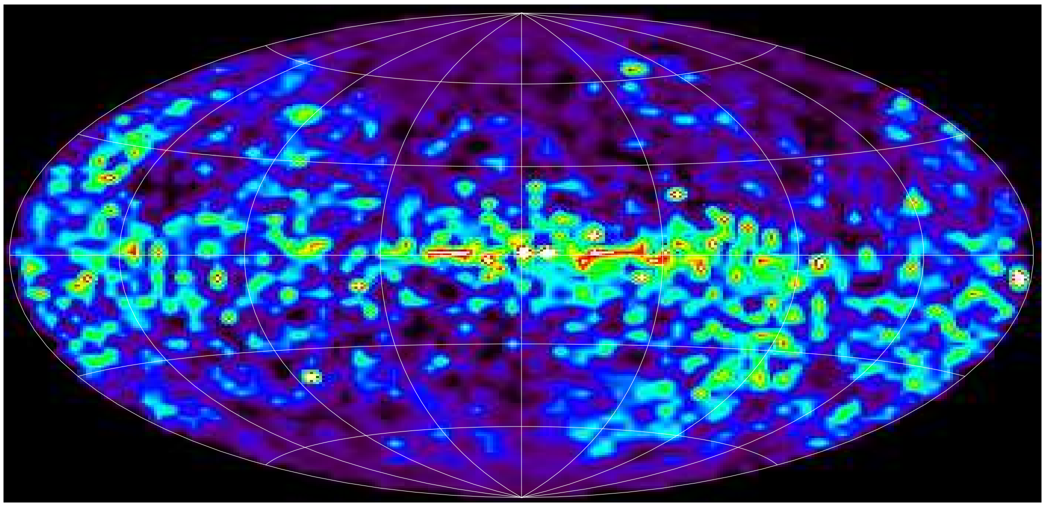
1. Description of method (following Section 2)
2. Full skymaps, smoothed to 5^o (see Fig 1c), in each range and 1-30 MeV combined.
3. Background as function of observation (Fig 2: total only)
4. Latitude, longitude profile ($5^o \times 5^o$ binning) for each energy (selected from Fig 4)
5. Spectrum for $|b| < 5^o$ (see Fig 6)
6. Discussion of reliabiity, systematic uncertainties.
7. Comparison with Hans Bloemen's skymapping results..

7 Figures

1–3 MeV Cycle 1–6 SKYMOS/Cray T3E wide PSF Iter 49



3–10 MeV Cycle 1–6 SKYMOS/ Cray T3E wide PSF Iter 70



10–30 MeV Cycle 1–6 SKYMOS/ Cray T3E Iter 99

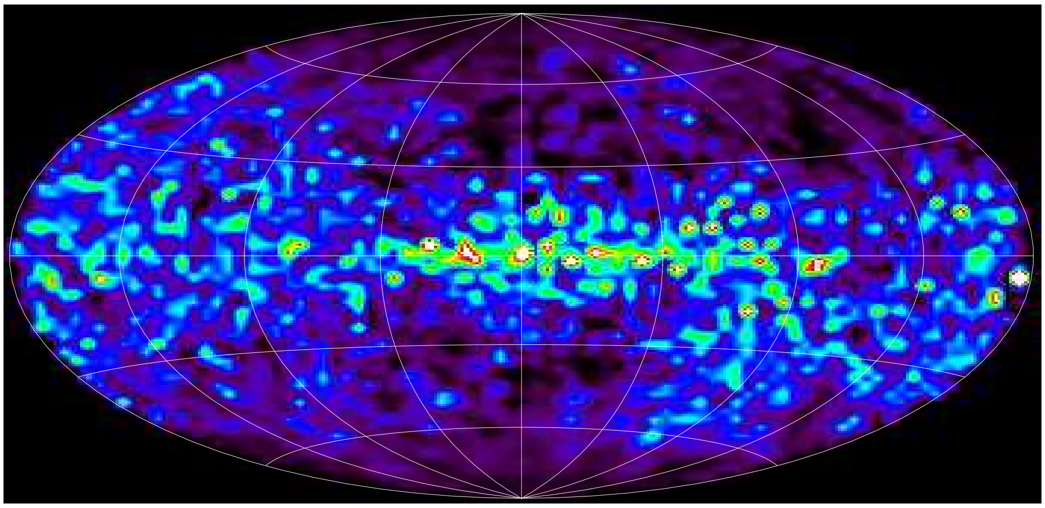
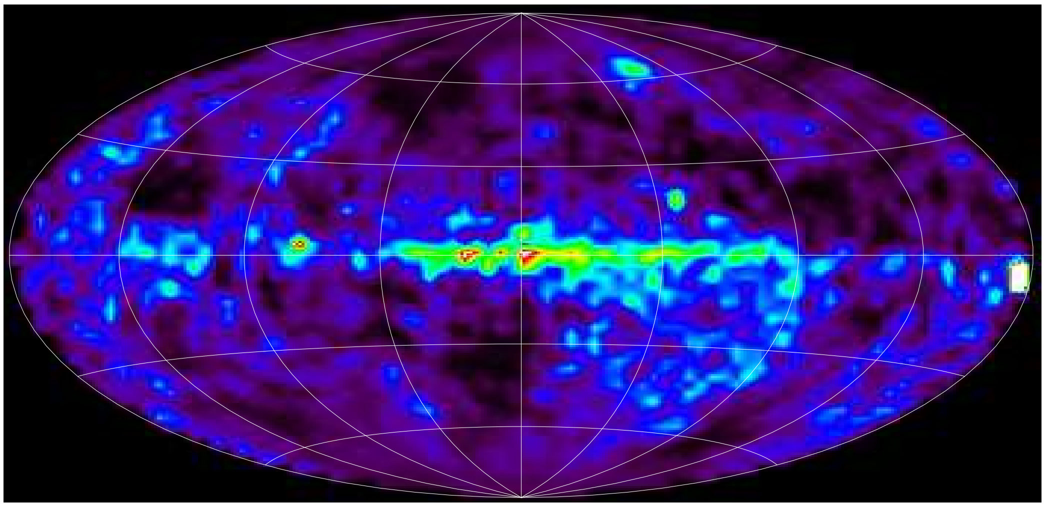
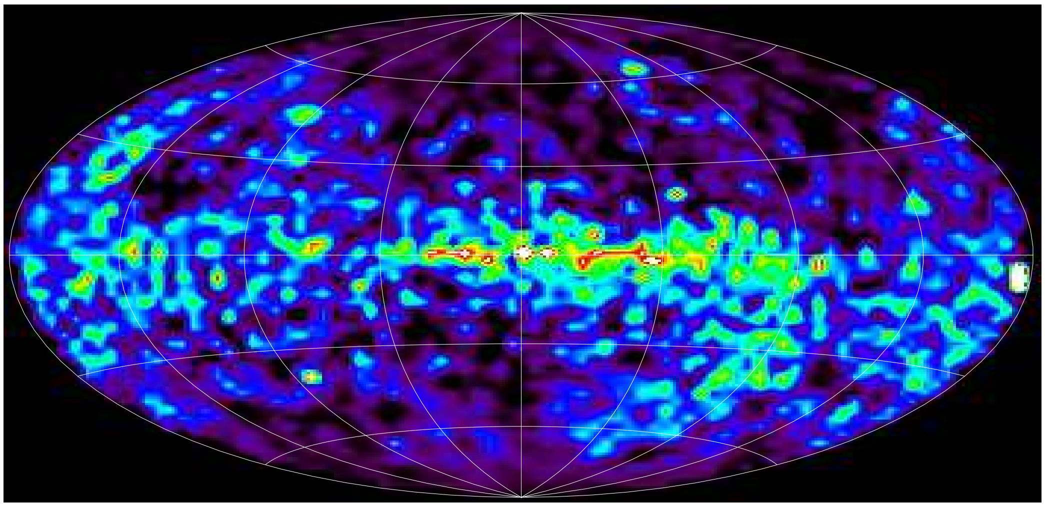


Fig 1a SKYMOS full sky images, unsmoothed

1–3 MeV Cycle 1–6 SKYMOS/Cray T3E wide PSF Iter 49



3–10 MeV Cycle 1–6 SKYMOS/ Cray T3E wide PSF Iter 70



10–30 MeV Cycle 1–6 SKYMOS/ Cray T3E Iter 99

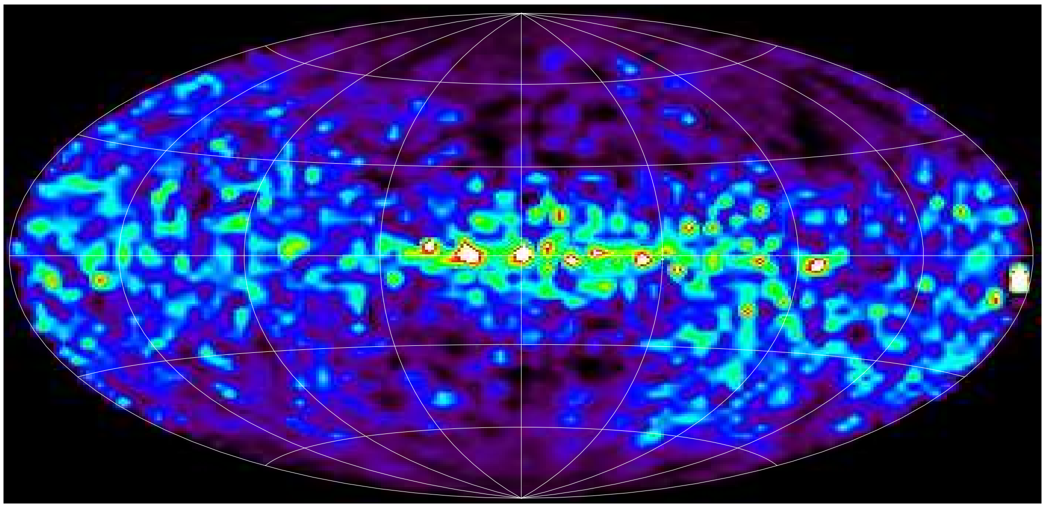
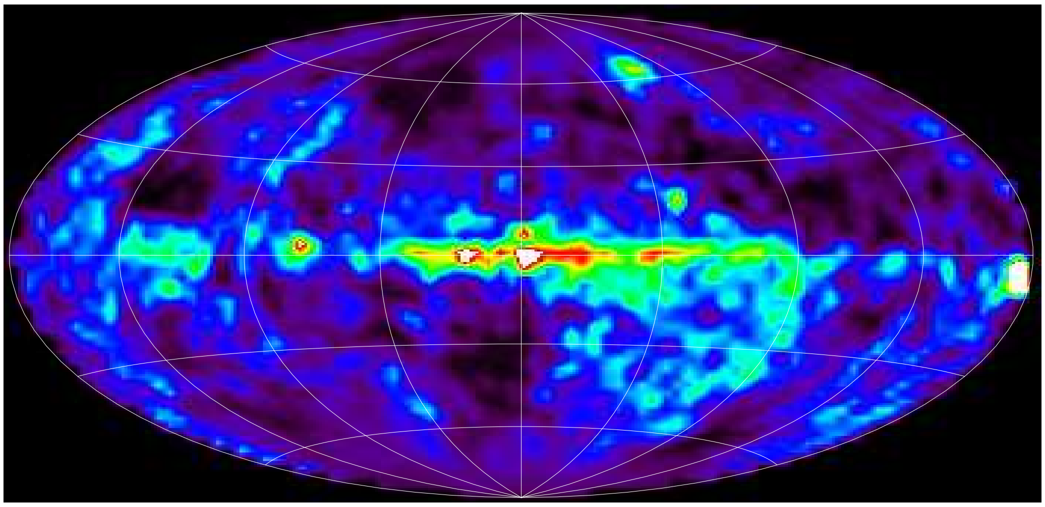
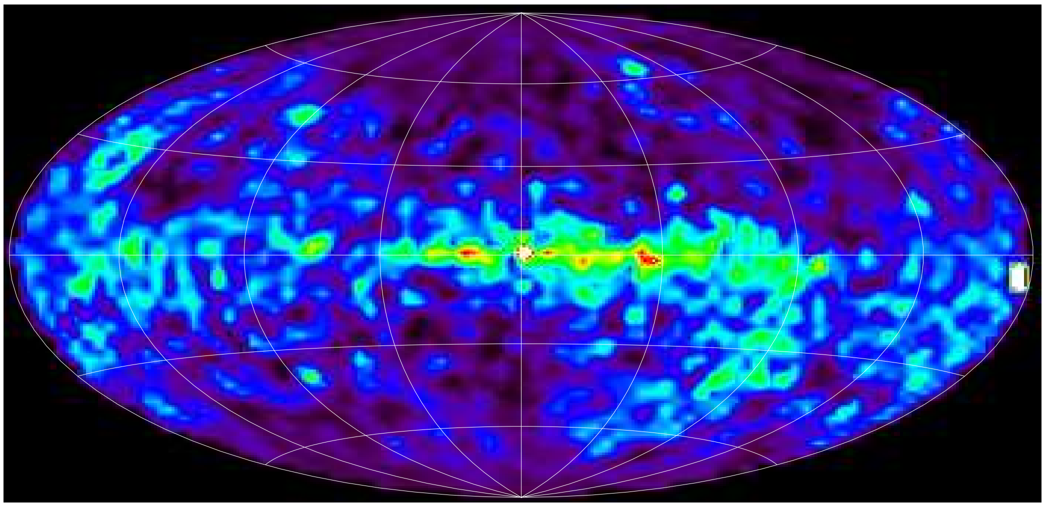


Fig 1b SKYMOS full sky images, smoothed to 3°.

1–3 MeV Cycle 1–6 SKYMOS/Cray T3E wide PSF Iter 49



3–10 MeV Cycle 1–6 SKYMOS/ Cray T3E wide PSF Iter 70



10–30 MeV Cycle 1–6 SKYMOS/ Cray T3E Iter 99

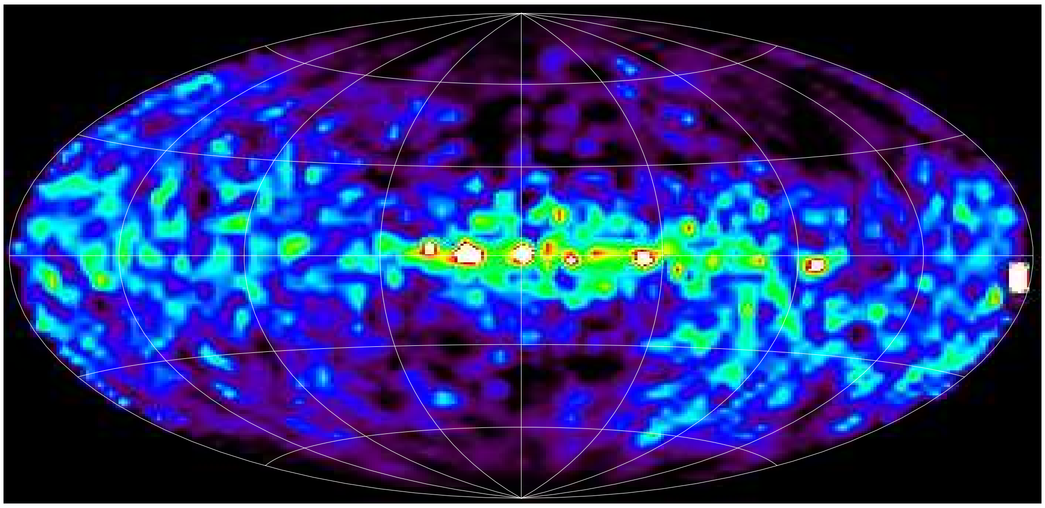


Fig 1c SKYMOS full sky images, smoothed to 5^o.

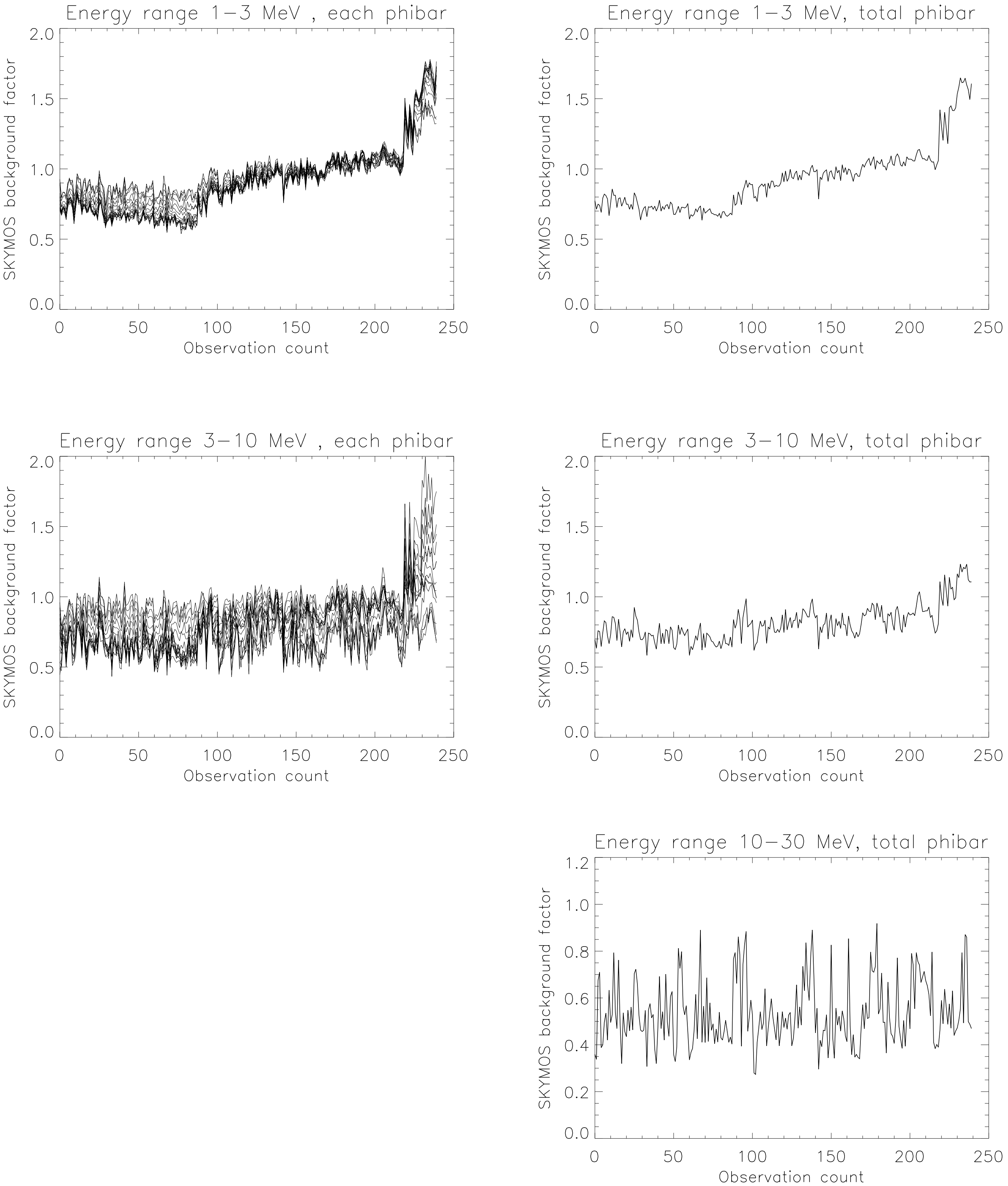


Fig 2: Background scaling factor as function of observation, per $\overline{\varphi}$ layer (left) and total (right)

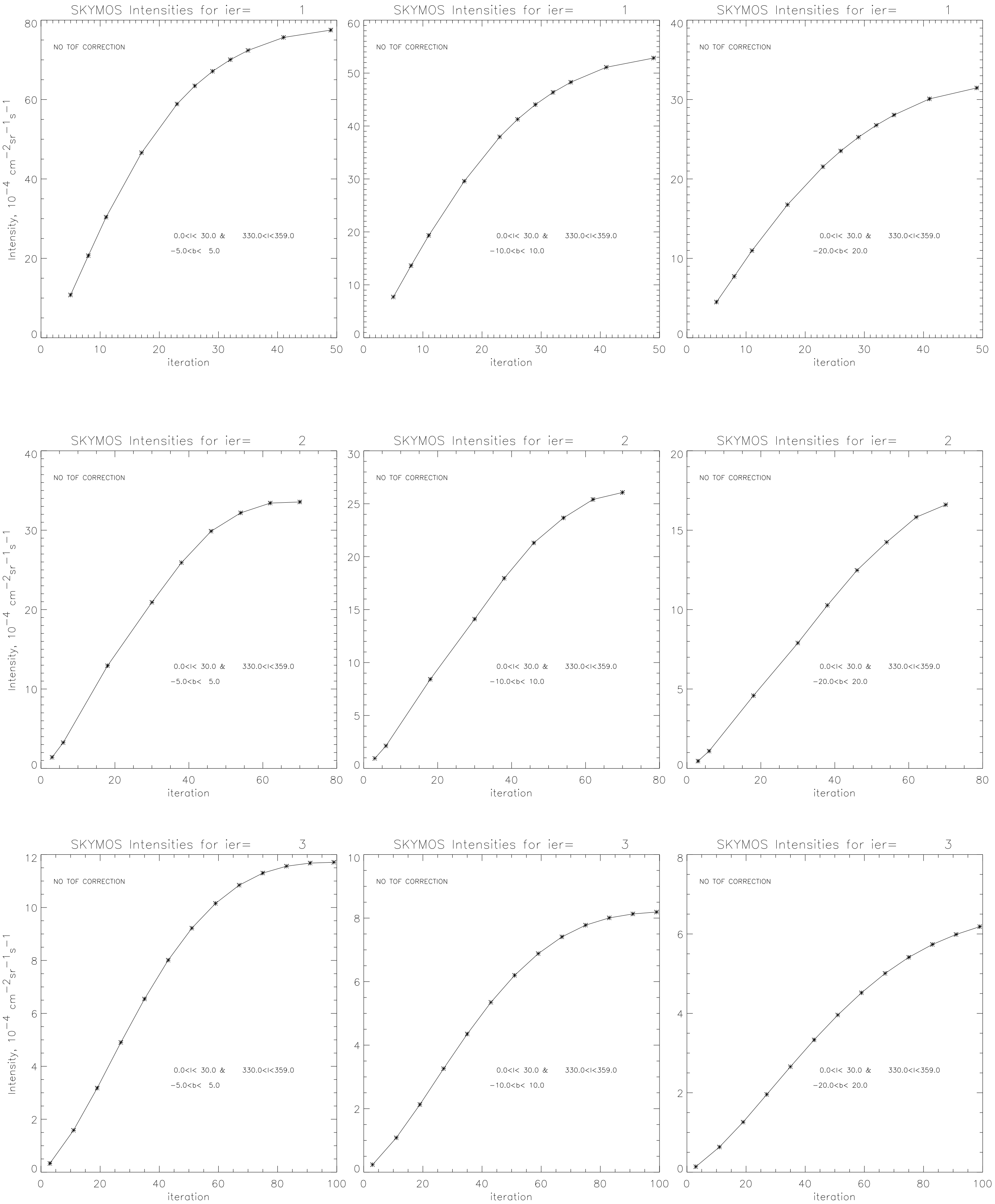


Fig 3: Average intensity of inner Galaxy as function of iteration, for $|b| < 5^o, 10^o, 20^o$

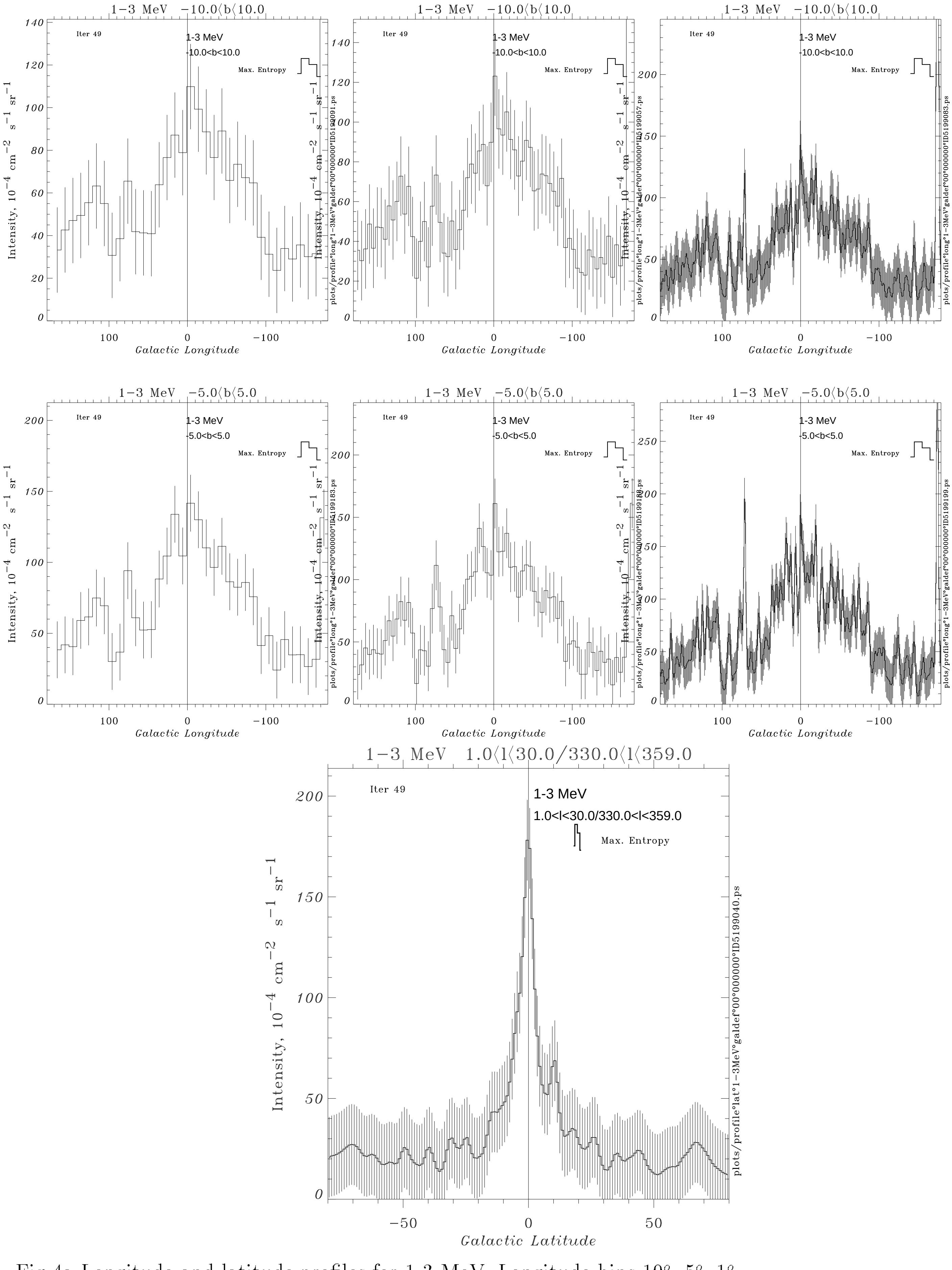


Fig 4a Longitude and latitude profiles for 1-3 MeV. Longitude bins 10^o, 5^o, 1^o

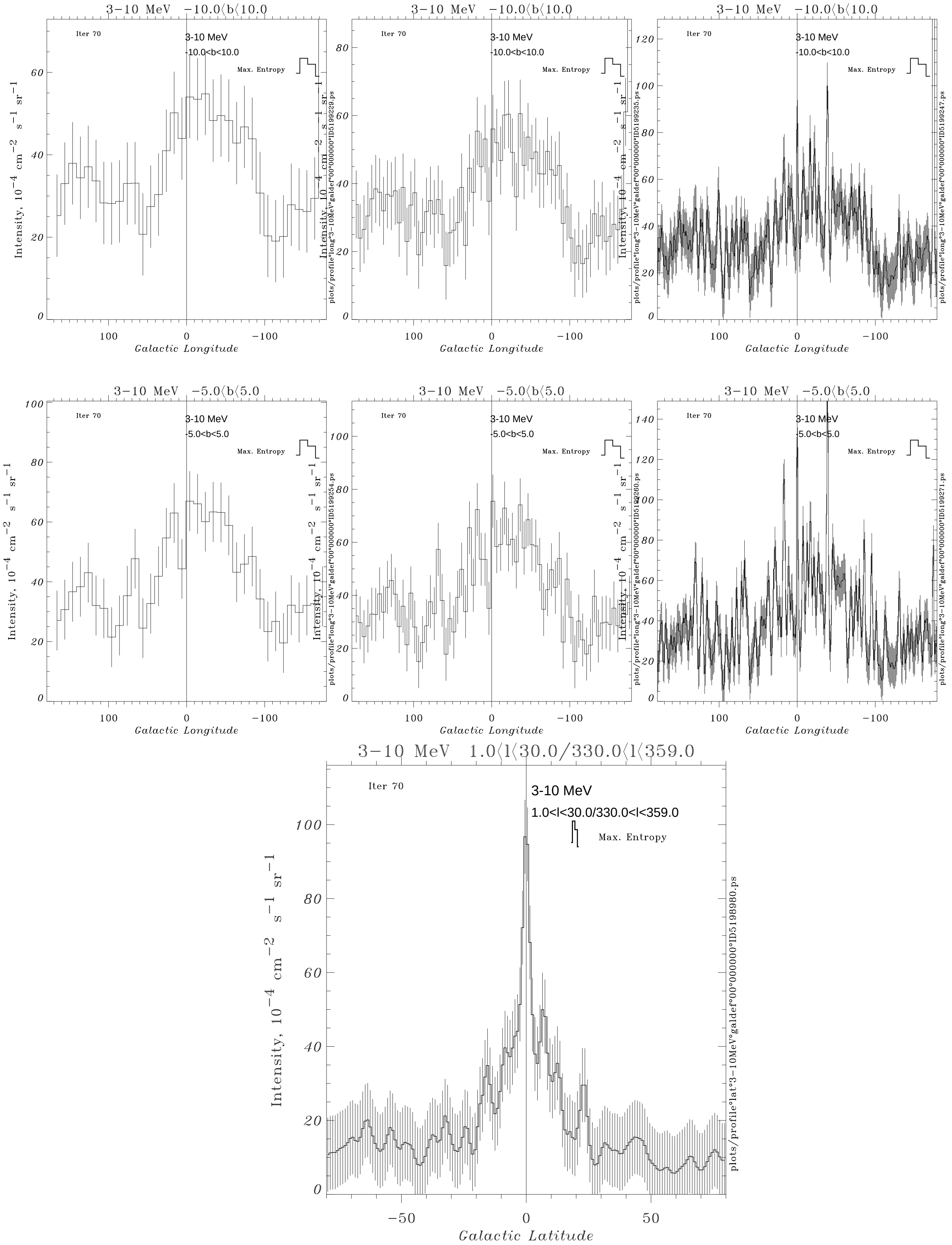


Fig 4b Longitude and latitude profiles for 3-10 MeV. Longitude bins 10^o, 5^o, 1^o

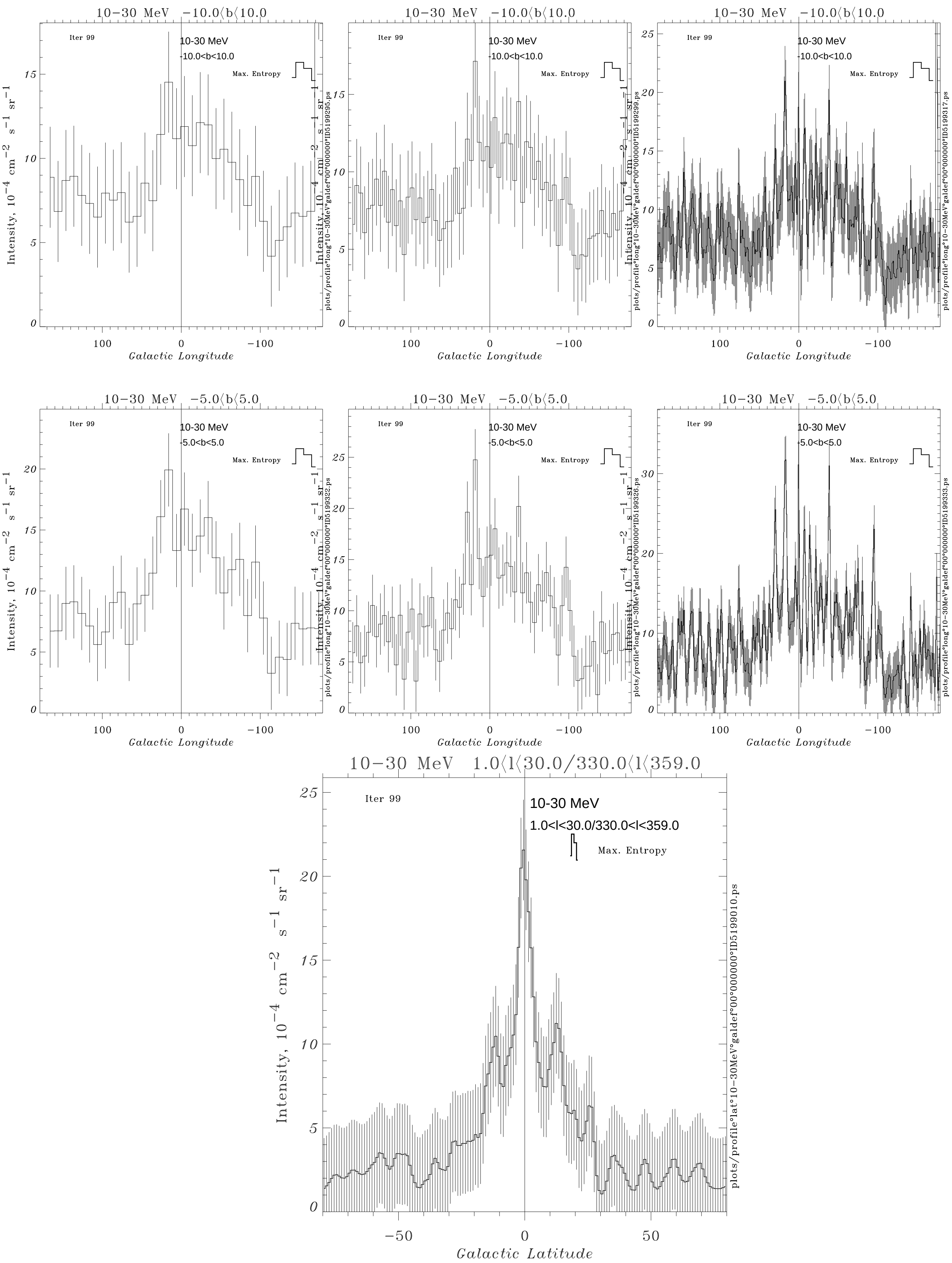


Fig 4c Longitude and latitude profiles for 10-30 MeV. Longitude bins 10^o, 5^o, 1^o

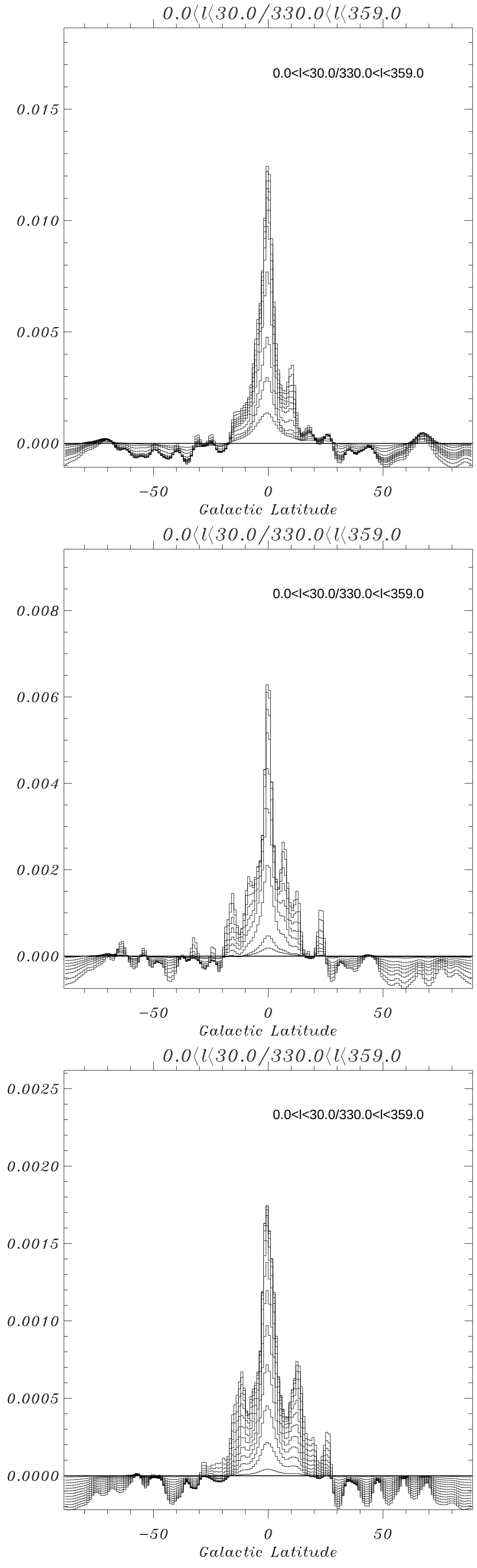


Fig 5. latitude profiles as function of iteration for $330^o < |l| < 30^o$. Intensities relative to $30^o < |b| < 70^o$, all l

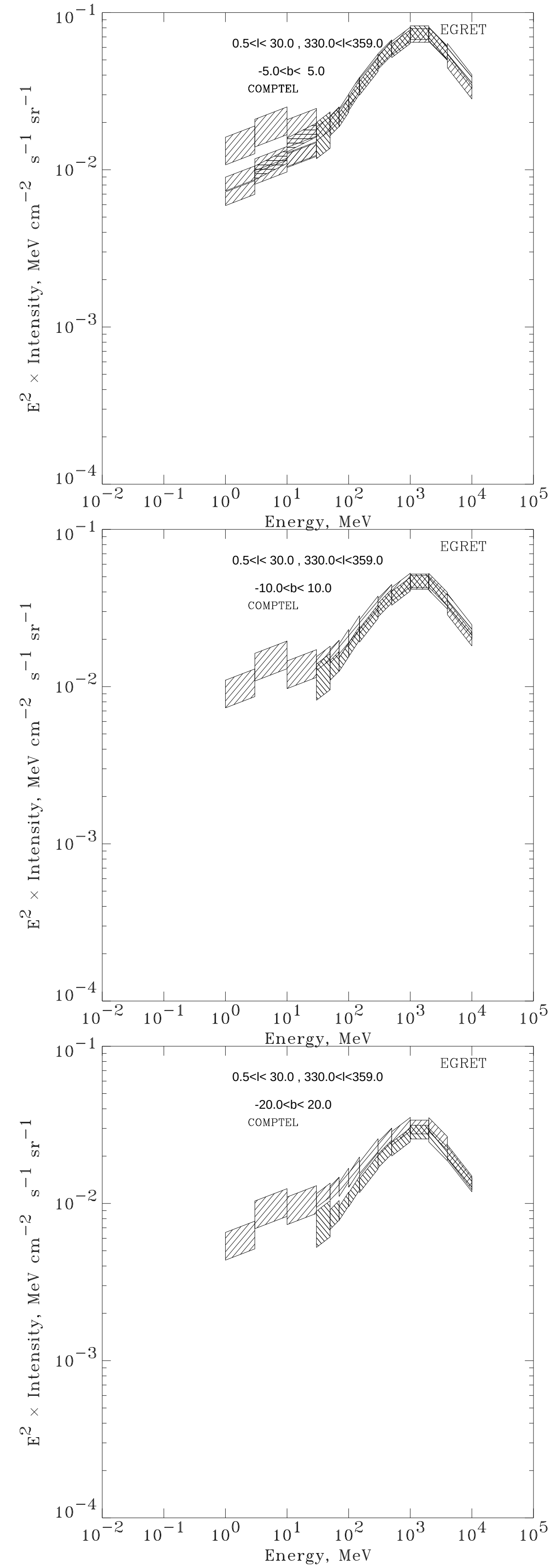


Fig 6. Spectra of inner Galaxy for various latitude ranges.
For $|b| < 5^o$ the spectra from Strong et al. 4th Compton Symposium are also shown.