THE COMPTEL 1.809 MEV SURVEY

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ABSTRACT

We present the latest update of the 1.809 MeV sky survey obtained with COMPTEL. Based on all observations taken since the launch of CGRO in spring 1991 to early summer this year we obtain 1.809 MeV all sky maps using different imaging methods. The background is modelled on the basis of an adjacent energy approach. We confirm the previously reported characteristics of the galactic 1.809 MeV emission, specifically excesses in regions away from the inner Galaxy.

The observed 1.8 MeV $\gamma$-ray line is ascribed to the radioactive decay of $^{26}$Al in the interstellar medium. $^{26}$Al has been found to be predominantly synthesised in massive stars and their subsequent core-collapse supernovae, which is confirmed in tracer comparisons. Due to this, one anticipates flux enhancements aligned with regions of recent star formation, such as apparently observed in the Cygnus and Vela regions.

Key words: COMPTEL; gamma-rays; $^{26}$Al.

1. INTRODUCTION

The imaging gamma-ray telescope COMPTEL (Schönfelder et al., 1993) aboard NASA’s CGRO spacecraft allowed for the first time to survey the entire sky in the MeV regime. One of the mission highlights is the generation of the first all-sky images of the 1.809 MeV gamma-ray line emission, first detected by Mahoney et al. (1982) using HEAO-C. This emission line is attributed to the radioactive decay of $^{26}$Al with a lifetime of 1.04 Myr. The first 1.809 MeV all-sky map based on the first three years of COMPTEL observations was presented by Oberlack et al. (1996). This image was based on a maximum entropy deconvolution method (ME) (Strong et al., 1992) applying an adjacent energy background model (Oberlack et al., 1996; Knödlseder et al., 1996) to the individual observation periods. This map confirmed the non-local character of the detected 1.809 MeV emission, as already seen in a first Galactic plane survey (Diehl et al., 1995) and confirmed later in the 5 year image of Oberlack (1997). We attribute most of the emission to young, massive stars and active star forming regions.

The maximum entropy deconvolution shows a tendency for highly structured images (Oberlack, 1997; Knödlseder, 1997). Other image reconstruction methods have been developed and applied to the COMPTEL data. Knödlseder et al. (1999) introduced a multi-resolution regularised expectation maximisation algorithm (MREM) using a wavelet filtering for noise suppression. Although the MREM images are much less structured than the ME maps, the previously reported emission characteristics are confirmed. Possibly the MREM approach is somewhat conservative with respect to image structures whereas the maximum entropy images still may include artifacts.

In addition to these imaging approaches, which make use of the adjacent energy background described below, Bloemen et al. (1999) showed an alternative approach. They use an iterative model fitting method combined with a maximum entropy imaging of the residual emission in neighbouring energy bands to construct an appropriate background model, which is finally used for the maximum entropy imaging in the line energy regime. A comparison to the cycle 1-5 image (Oberlack, 1997), from the same COMPTEL data, shows an underestimation of the deduced fluxes by applying the adjacent energy background instead of the iterative modell fitting. Yet, the reported image structures are rather identical. Application of maximum entropy and MREM imaging to seven years of COMPTEL data with a refined adjacent energy background model again confirms the chief image features (Plüschke et al., 2000a). After termination of the CGRO mission end of May this year we now present results using the complete
mission database. The following section summarises the 1.809 MeV data processing, followed by a presentation of the maximum entropy and multi-resolution images. Finally we discuss tests of possible systematic effects on the imaging results.

2. DATA ANALYSIS & BACKGROUND TREATMENT

In this analysis we use all data from beginning of the mission up to its end, from May 1991 to end of May 2000, split into ∼ 350 observation periods with typical durations of one to four weeks. The accumulated effective observation time ranges from 0.27 to 4.20 · 10^7 s, which results in a sensitivity in the 1.809 MeV regime of 0.8 to 1.4 · 10^{-5} ph cm^{-2} s^{-1}, depending on location.

For the imaging analysis the event data from a 200 keV wide energy band around the 1.8 MeV line are binned in a 3-dimensional data space, which is spanned by scatter direction of the photon between the two detector layers inside the telescope and the scatter angle resulting from the Compton kinematics. A more detailed description of the data space and the event selection criteria can be found in Oberlack (1997). The instrument characteristics in the energy regime are summarised in a energy resolution of 140 keV (FWHM) and an angular resolution of 3.8° (FWHM).

Instrumental background strongly disturbs the observation data. The effective signal to noise ratio is of the order 1%, so accurate background modelling is crucial in analysing COMPTEL data. In the case of gamma-ray line analysis the use of adjacent energy bands for background deduction appears to be natural. To account for time dependent variations of the background the model is estimated on an observation period basis and summed afterwards. To suppress statistical fluctuations each background model is smoothed by a local chi-square fit to the geometry function. This accounts for the original event selection characteristics of the specific observation periods and guarantees an accurate treatment also in the galactic polar region.

A longterm study by Oberlack (1997) of count-ratios in the line energy band relative narrow adjacent energy bands showed a clear time-dependence. This time-variability can be traced to a build up ^{22}Na during the mission, affecting the spectral shape in the vicinity of the ^{20}Al line. Weidenspointner et al. (2000) identified instrumental background components due to 8 radioactive isotopes, with ^{22}Na and ^{24}Na being the strongest among them. Both isotopes originate from activation in the structure elements of COMPTEL and CGRO. The longer lived isotope ^{22}Na shows a build up whereas ^{24}Na is responsible for short-time variations. Oberlack (1997) determined the contributions of these two isotopes per observation period by fitting the spectra using appropriate templates. During the early mission this procedure restores the background normalisation quite well. In the later mission phases, especially after the second reboost of CGRO spacecraft, the additional isotopes must be taken into account to obtain an adequate representation. This is because of the more efficient activation in the higher altitude orbits. Figure 1 shows the background normalisation as function of the mission time for both cases.

3. THE 1.809 MEV MAPS

Following the analysis of Plüschke et al. (2000a) we applied both image reconstruction methods to our prepared data. We used the maximum entropy algorithm (see Strong et al. (1992)), which iteratively extracts the sky intensity distribution being compatible with the data. As already reported earlier, the ME method shows a clear tendency to create a lumpy, structured image in late iterations. On the other hand the early iterations significantly underestimate the gamma-ray fluxes. Therefore an intermediate iteration has been chosen as a compromise between flux reproduction and map smoothness (see figure 2).

Alternatively, we applied the MREM technique to our data. The MREM algorithm is based on an iterative expectation maximisation scheme accompanied by a wavelet filtering algorithm. This wavelet filter suppresses the features of low significance and artifacts by applying a user-adjustable threshold. By controlling the changes in the restructured flux distribution this method becomes convergent. The MREM algorithm attempts to produce the smoothest image being consistent with the given data (see Knödlseder (1997); Knödlseder et al. (1999)). Figure 3 shows the equivalent MREM image of the COMPTEL data.

Both image reconstructions show an extended galactic ridge emission mostly concentrated towards the galactic center region (|l| ≤ 30°), plus an emission feature in the Cygnus region, and a low-intensity ridge along Carina and Vela. These characteristics confirm again the previously reported emission structures. In addition the maximum entropy image shows some low-intensity features in the longitude range between 110° and 270°. Also at latitudes beyond ±30° some of these features are visible. These
features and their significance are subject to further studies.

4. SYSTEMATICS

Figure 4 shows the maximum entropy image generated by Oberlack (1997) from the first five years of COMPTEL observations. A comparison with figure 2 reveals only minor differences. The two most obvious differences are the variation of the shape of the Cygnus feature and the broader appearance of the emission in the complete mission image.

Due to the large field of view the COMPTEL observations covered the full sky and accumulated very long effective observation times for each sky pixel. Nevertheless the effective observation time varies over one order of magnitude. Even when the point spread function is taken into account the exposure varies within a factor of 2. These imperfections of the exposure may affect the imaging results due to existing gradients (Oberlack, 1997). To investigate these possible effects we selected observation periods so that the summed data gives an exposure as even as possible. Due to a rather uneven exposure near the northern galactic pole compared to the southern hemisphere this is only possible for a band along the galactic equator with $|b| \leq 40^\circ$. A further restriction is given by the fact that at two positions in the galactic plane near $l \approx 140^\circ$ and $l \approx 250^\circ$ the exposure is only filled due to the large field of view, no real observations pointing in these directions have been undertaken. So a small gradient in the selected data still remains.

The upper panel of figure 5 shows the exposure resulting from the selected observation periods whereas the lower panel shows the deduced maximum entropy image of these observations. A comparison of the resulting image with figure 2 reveals no real differences in the appearing features. Only the latitude extent of the selected data image appears smaller than in the complete mission map, which could be understood in perspective of the limitation of the selected viewing periods to be restricted to pointings near the galactic plane.
5. SUMMARY

We have presented the COMPTEL 1.809 MeV all-sky maps based on the complete mission database. COMPTEL reached an accumulated sensitivity in the 1.809 MeV regime of 0.8 to $1.4 \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$. The maps confirm the previously reported emission characteristics - an extended ridge concentrated towards the galactic center, a peculiar emission feature in the Cygnus region (Plüschke et al., 2000b) and a low-intensity ridge in the Carina-Vela (Diehl et al., 2000) region. In addition, the maximum entropy deconvolution gives some low-intensity features which are suppressed in the MREM images. These features may be artifacts. A small number of these features on the other hand appear in all earlier maximum entropy maps at the same position, which gives some confidence in the reality of these emission features. INTEGRAL will possibly allow a further study of these features.

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