A New Look at Image Reconstruction of COMPTEL 1.8 MeV Data

J. Knödlseder¹, D. Dixon⁶, R. Diehl², U. Oberlack⁵, P. von Ballmoos¹, H. Bloemen³, W. Hermsen³, A. Iyudin², J. Ryan⁴, and V. Schönfelder²

¹Centre d’Etude Spatiale des Rayonnements, CNRS/UPS, B.P. 4346, 31028 Toulouse Cedex 4, France
²Max-Planck-Institut für extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany
³SRON-Utrecht, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands
⁴Space Science Center, University of New Hampshire, Durham NH 03824, U.S.A.
⁵Astrophysics Laboratory, Columbia University, New York, NY 10027, U.S.A.
⁶Institute for Geophysics and Planetary Physics, University of California, Riverside, CA 92521, U.S.A.

ABSTRACT Deconvolving COMPTEL γ-ray data into images presents a major methodological challenge. We developed a new algorithm called Multiresolution Regularized Expectation Maximization (MREM), which explicitly accounts for spatial correlations in the image by using wavelets (Dixon et al. 1998). We demonstrate that MREM largely suppresses image noise in the reconstruction, showing only significant structures that are present in the data. Application to 1.8 MeV data results in a sky map that is much smoother than the maximum entropy reconstructions presented previously, but it shows the same characteristic emission features which have been established earlier.

KEYWORDS: image reconstruction; gamma-ray lines; wavelets

1. INTRODUCTION

Imaging the γ-ray sky at MeV energies is one of the important milestones achieved by the COMPTEL telescope aboard the Compton Gamma-Ray Observatory (CGRO). In particular, COMPTEL provided the first image of the sky in the light of the 1.809 MeV γ-ray line radiation, attributed to radioactive decay of ²⁶Al (Diehl et al. 1995; Oberlack et al. 1996). Reconstruction of intensity distributions from the complexly encoded COMPTEL data requires a deconvolution procedure. The sky maps presented in previous works were generally obtained using a maximum entropy (ME) algorithm (Strong et al. 1992). Starting from a grey image, ME iteratively solves for a maximum entropy solution with increasingly structure entering the reconstruction as the iterations proceed. Unfortunately, there is no objective criterion where to stop the iterations, and the resulting image depends on the choice of the data analyst. Additionally, it has been shown that the reconstructions are very sensitive to statistical noise in the data, leading to lumpy images even in the presence of a smooth and structureless γ-ray intensity distribution (Knödlseder et al. 1996).
For these reasons, we developed a new algorithm called *Multiresolution Regularized Expectation Maximization*, which explicitly accounts for spatial correlations in the reconstructed image by using wavelets. This effectively reduces the number of free parameters in the reconstruction process which is at the origin of the lumpy aspect of ME images. MREM is based on the Richardson-Lucy algorithm (Richardson 1972; Lucy 1974) which is a special case of the more general class of expectation maximization (EM) algorithms (Dempster et al. 1977). We introduced an additional wavelet thresholding step in the iterative EM scheme which aims to extract the significant structure in the reconstruction. This leads to a convergent algorithm which automatically stops when the significant structure has been extracted from the data. For a detailed description and discussion of the algorithm the reader is referred to Dixon et al. (1998).

2. SIMULATIONS

To illustrate the performance of MREM with respect to ME we apply both algorithms to simulated COMPTEL observations of (1) an exponential disk distribution normalized to $3M_\odot$ of total galactic $^{26}$Al mass, and (2) the EGRET $>100$ MeV all-sky map adjusted to a plausible 1.809 MeV intensity level by fitting to COMPTEL 1.8 MeV data. The first case tests the response to a smooth and structureless intensity distribution while the second case is probably a more realistic situation with some point sources embedded in a structured diffuse emission distribution. The resulting all-sky maps and longitude profiles are shown in Fig. 1. It is clearly visible that in both cases ME leads to lumpy reconstructions. In particular, only few emission spots in the reconstruction of the EGRET sky map coincide indeed with real sources – most of the spots are artefacts due to statistical noise, appearing arbitrarily along the galactic plane. MREM drastically improves above ME in that it reasonably reconstructs the emission profiles without introducing artificial hot spots. The latitude extent of the reconstructions is slightly higher than that of the models, but this is a combined result of the instrument’s angular resolution of only 4° (FWHM) together with a low signal to noise ratio. Yet, e.g. the extended diffuse emission above the galactic center is still recovered in the EGRET MREM map.

3. THE COMPTEL 1.8 MeV SKY

The COMPTEL 1.8 MeV all-sky images obtained by ME and MREM are presented in Fig. 2. The ME reconstruction shows the typical lumpiness and hot spots which have also been seen for the exponential disk or EGRET map simulations. We cannot decide which of the lumps may correspond to real emission and which are artefacts of the ME deconvolution, but comparison to the simulations suggests that many of them are not real. The MREM image avoids this confusion, and shows a much smoother intensity profile with notable asymmetries with respect to
FIGURE 1. Image reconstruction of two mock dataset assuming an exponential disk (left column) and the EGRET $> 100$ MeV all-sky map (right column) as source model. The bottom panels show the resulting longitude profiles integrated over galactic latitudes of $|b| < 30^\circ$ (solid: model, dotted: ME, dashed: MREM).

the galactic center. There is a sharp emission cut at $l = 30^\circ$ in contrast to a long emission tail out to $l = -120^\circ$. A prominent diffuse emission feature is seen in the Cygnus region, a weaker diffuse emission spots is located near the anticenter. However, the excess emission in Carina ($l = -75^\circ$) and Vela ($l = -95^\circ$), which is seen in the ME map, is almost imperceptible in the MREM map.

4. CONCLUSIONS

An alternative COMPTEL 1.8 MeV all-sky image is presented in this paper which has been derived using a multiresolution reconstruction algorithm based on wavelets. Simulations suggest that our new algorithm provides a more reliable
reconstruction of diffuse and smooth $\gamma$-ray emission than the maximum entropy algorithm which has been used before. In particular, the number of 'hot spots' and the lumpiness of the 1.8 MeV image is largely reduced with respect to the ME map, but some irregularities persist. The simulations indicate that weak (3-4$\sigma$) point sources embedded in diffuse emission are not recovered by the algorithm, which explains the absence of prominent emission features in the MREM map towards Carina and Vela. In this sense the algorithm is biased towards smoothness since it prefers explaining structures by smooth emission rather than point sources if the data are consistent with both. MREM and ME are therefore complementary analysis tools, one clearly extracting the extended emission, the other providing hints for additional point-like emission.

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