The spectrum of diffuse Galactic continuum gamma rays measured by COMPTEL

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ABSTRACT

Diffuse Galactic continuum γ-ray emission in the 0.75-30 MeV range from the whole sky has been studied using COMPTEL data from the first 3 years of of the Compton Observatory. The imaging properties of COMPTEL enable spatial analysis of the γ-ray distribution using model fitting. A model based on gas and inverse-Compton distributions in the Galaxy has been used to derive the intensity spectrum of the γ-ray emission in the inner Galaxy. We find evidence for a component with a wider latitude distribution than the gas. The spectrum is compared with theoretical estimates of bremsstrahlung and inverse-Compton scattering.

1. INTRODUCTION

The diffuse continuum γ-ray emission from the Galactic plane at MeV energies is believed to originate in bremsstrahlung interactions of cosmic-ray electrons with interstellar gas and inverse-Compton interactions with the interstellar radiation field. Measurement of the γ-ray spectrum at low energies therefore provides important constraints on the spectrum and propagation of cosmic-ray electrons. This information is complementary to results from radio synchrotron and direct measurements of electrons.

The COMPTEL instrument on the Compton Observatory has sufficient imaging capability to allow a sensitive measurement of the diffuse radiation. Results have been published based on the first 15 months (Phase 1) of the Compton Observatory mission [1]. It was shown that the Galaxy is detected with high significance, and model fitting to the total column density of hydrogen gas (as measured by HI and CO surveys) was used to determine the emissivity spectrum; this was then compared with theoretical predictions for bremsstrahlung emission.

Recent developments in the analysis will be reported here. First, data from Phases 1, 2 and 3 of the mission increase the size of the database by a factor $\approx$2.5 and improves significantly the sky-coverage. Secondly, methods have been developed to analyse *full-sky* datasets, so that all the data contribute to the result - previous analyses were restricted to $|b| < 40^o$. This is important because of the wide field of view of COMPTEL. Third, the inverse-Compton component is included; estimates indicate that it may be substantial [2,3,4] so that its inclusion is a logical next step in the analysis. In this status report we concentrate on the intensity spectrum of the inner Galaxy; the inclusion of several components in the fits ensures that the intensities based on the model fitting will be more reliable than the precise decomposition into components.

Fig 1 shows full-sky images of the MeV gamma-ray sky from COMPTEL Phase 1+2+3 data, made with the maximum-entropy method [5]; for more details see [6]. The Galactic plane stands out clearly in all energy ranges, indicating that we are detecting large-scale emission from the Galaxy.

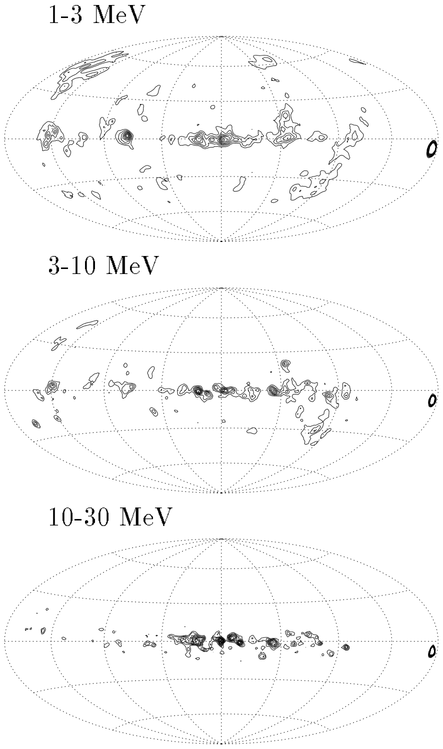

Fig 1: Maximum-entropy images of the whole sky in the 1-3, 3-10 and 10-30 MeV ranges based on Phase 1+2+3 data [5],[6]. Coordinates are Galactic centered on l=0 .

2. OBSERVATIONS and METHOD

The full database from Phase 1, 2 and 3 was used for this analysis. Only the long Virgo observation in Phase 3 was excluded as giving excessive weight to one high-latitude region. The principles of COMPTEL measurements are given in detail in [7]. For each incident photon detected by the instrument, the energy deposits and interaction locations in the upper and lower detectors are measured. The Compton scatter angle $\bar{\varphi}$ is computed from the measured energy deposits, and the photons are binned in a 3-D dataspace consisting of the scatter direction and $\bar{\varphi}$. The response of the instrument in this dataspace to a given incident γ-ray intensity distribution is computed on the basis of the knowledge of the instrument configuration as a function of time, the pre-launch calibration and simulations. Hence, given a parameterized model of the sky, the values of the parameters can be determined by model fitting in the dataspace described above.

We assume the continuum radiation originates in cosmic-ray interactions with interstellar gas and radiation fields, and therefore use the relation

$$I_\gamma = \frac{q}{4\pi}(N_{HI} + 2X_{co}W_{co}) + f_{ics}I_{ics} + I_B \tag{1}$$

where I_γ is the γ-ray intensity (cm^{-2} sr^{-1} s^{-1}), q is the γ-ray emissivity per H atom, N_{HI} is the atomic hydrogen gas column density, W_{co} is the integrated CO temperature and I_B is a celestial background term. As usual we assume that the molecular hydrogen column density is related to the integrated CO temperature by $N_{H_2}/W_{co} = X_{co}$, either with X_{co}=2.3 10^{20} molecules cm^{-2} (K km s^{-1})$^{-1}$ as determined from COS-B data [8] and supported by various other methods [9,10] or with

X_{co} as a free parameter. I_{ics} is a model-based inverse-Compton intensity [2,12] and f_{ics} is a scale factor. The free parameters of the model are q, X_{co} (optionally), f_{ics} and I_B. The (dominant) instrumental background was not explicitly modelled for these preliminary results and is here predominantly assigned to the isotropic (I_B) term; new studies (in progress) using explicit modelling are however found to substantiate the present conclusions, and will be the basis for future work.

The intensities were computed by averaging the sum of the fitted components over $300^o < l < 60^o$ and integrating over $|b| < 20^o$.

3. GAMMA-RAY INTENSITY SPECTRUM

The intensity spectrum based on a model with X_{co}=2.3 10^{20} is shown in Fig 2. The new results are consistent with the analysis based on Phase I only [1] but the larger amount of data, full sky coverage and more extensive model mean that they are more reliable. The COMPTEL points are consistent with a spectral index of -2.0 and this slope is used to convert the values for each energy range to a differential spectrum in this plot. Exactly the same fitting procedure was applied to COS-B data [8] so that it is meaningful to combine the spectra from the two instruments, and the resulting spectrum should be dependable over the range 1 MeV to 1 GeV. The MeV intensities are consistent with a smooth connection to the COS-B spectrum. SIGMA results [11] extend the spectrum down to 50 keV. The latitude profile of the 1-3 MeV intensity of the model components in the inner Galaxy is shown in Fig 3.

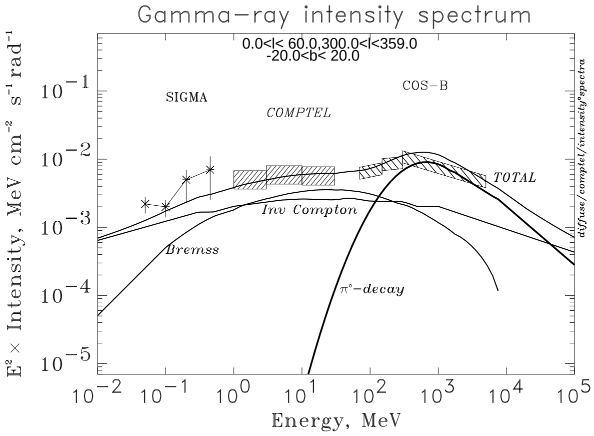

Fig 2: Intensity spectrum of the inner Galaxy $300^o < l < 60^o$, integrated over $|b| < 20^o$ derived from COMPTEL data together with values from COS-B [8].SIGMA results for the region around $l=315^o$ [11] are also indicated. A theoretical synthesis of the spectrum from bremsstrahlung, inverse-Compton and π^o-decay components is shown.

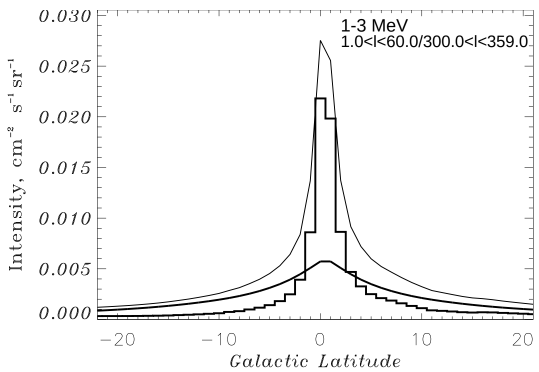

Fig 3: Latitude profile of 1-3 MeV intensity in the inner Galaxy $300^o < l < 60^o$, corresponding to the model fit to the COMPTEL data. The components are: bremsstrahlung (histogram), inverse-Compton (lower curve), total (upper curve)

We find that the inclusion of the inverse-Compton component improves the fits very significantly in each energy range; this demonstrates at least the presence of a component with a broader latitude distribution than the gas; whether it is indeed inverse-Compton or some other broad emission for example related to local Galactic structure cannot yet be finally decided on the basis of the presently available evidence. The fitted inverse-Compton component is quite close to the theoretical expectation ($f_{ics} \approx 1-2$). In view of the considerable uncertainties in this prediction (the distribution of electrons, the ISRF) , this is quite satisfactory. While this agreement with the model is encouraging, we regard the total fitted intensities as more reliable than the exact decomposition into components at this stage. We find that the intensity spectrum is not very sensitive to the details of the model used, so that this can be regarded as a deconvolution technique for obtaining average intensities over areas of the sky, which can be directly compared with theoretical predictions.

4. BREMSSTRAHLUNG AND INVERSE COMPTON EMISSION

The low-energy interstellar electron spectrum is not directly measurable (due to solar modulation) so we have to rely on model calculations to obtain predictions of the γ-ray emissivity from bremsstrahlung. At higher energies (above 1 GeV) the situation is easier due to the validity of direct measurements of electrons, but the spatial dependence of the spectrum makes modelling nevertheless important. Electron spectra for diffusive halo models of cosmic-ray propagation have been calculated [12]. A halo scale height of 3 kpc and a diffusion coefficient D= 2.5 10^{28} cm^2 s^{-1} were used, chosen to be consistent with the cosmic-ray B/C ratio and ^{10}Be data. The bremsstrahlung prediction from this model is somewhat higher than the fits to the data indicate, so a factor 0.7 has been applied to this component in Fig 2. The inverse-Compton prediction is from [12]; the π^o emissivity is from [15]. Since the fits indicate that the inverse-Compton component is quite close to the theoretical expectation there is an independent plausibility argument for the decomposition illustrated in Fig 2. In the >100 MeV range the prediction is also in accord with the estimate of $\approx$10% inverse-Compton contribution based on COS-B data [8]. An argument *against* the present interpretation is the apparent clumpiness of the images which suggests a more patchy, perhaps local, origin for at least some of the emission [16]. Such clumpiness would not be expected on the basis of simple cosmic-ray/gas/ISRF interaction models, but could nevertheless be understood in the same context on the basis of the rapid energy losses of low-energy electrons which implies that they may not propagate far from their sources and thus reflect the uneven source distribution in the Galaxy. The computed inverse-Compton contribution extends with approximately an E^{-2} spectrum at least to 100 keV so that it may be dominant there; it appears to be consistent with the SIGMA detection of the plane in the 50-500 keV range [11]. The OSSE experiment on the Compton Observatory will also measure the spectrum in this region and provide a critical test of this model.

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