A PRELIMINARY EXPOSURE-MAP BASED COMPARISON OF SPI AND RHESSI ^{26}AL FLUX MEASUREMENTS

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ABSTRACT

Recently, first results regarding ^{26}Al flux from the Galaxy from both the INTEGRAL Spectrometer SPI and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) have become available. The two instruments' results are based on very different exposures of the Galaxy. While SPI is a coded aperture instrument with a massive BGO shield restricting its field of view (FoV) to $\sim 30°$, RHESSI's unshielded Ge detectors observe the whole sky. SPI's ^{26}Al measurement is based on pointed observations of the Galactic central region and background spectra from off-Galactic disk pointings; the RHESSI result is based on Earth occultation. RHESSI exposures cover a significantly larger sky area, specifically in Galactic latitude, compared to SPI's Galactic center deep exposure (GCDE). We check for systematic differences in measured fluxes from diffuse ^{26}Al emission in both experiments by testing the impact of different sky exposures on the respective results. We find that RHESSI's choice of "source" and "background" regions is critical, as well as the treatment of off-instrument axis ^{26}Al emission in SPI analysis.

Key words: INTEGRAL; SPI; RHESSI; nucleosynthesis; ^{26}Al; mapping; nuclear line imaging.

1. INTRODUCTION

Obtaining detailed information about the ^{26}Al distribution in our Galaxy constitutes an important step towards a better understanding of the origin of the elemental abundances in the solar system today. A good knowledge of both the amount and the spatial distribution of ^{26}Al will help to discriminate between different production sites and thus constrain models of nucleosynthesis. Several measurements of the ^{26}Al flux in the 1809 keV line from the "inner Galaxy" ($\pm 30°$ longitude) exist: SMM measured $4.2 \pm 0.4 \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ (Share et al., 1985), GRIS obtained $4.4^{+2.0}_{-1.8} \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ (Teegarden et al., 1991), and COMPTEL measured $2.8 \pm 0.15 \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ using a maximum entropy (MEM) reconstruction algorithm (Diehl et al., 2003). Given all experiments up to and including CGRO, an inner Galaxy ^{26}Al flux of $\sim 4.0 \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ seems most plausible (Diehl and Timmes, 1998).

Recently, high spectral-resolution measurements from two new space missions with similar detector units have become available: from the INTEGRAL Spectrometer SPI (Vedrenne et al., 2003) and from the solar observatory RHESSI (Lin et al., 2002). RHESSI measures a total 1809 keV line flux from the inner Galaxy of $3.69 \pm 0.27 \pm 0.11 \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ (Smith, 2004); this flux is calculated on the assumption that all ^{26}Al emission is constrained to the inner Galaxy (here defined as $\pm 30°$ longitude and $\pm 5°$ latitude). SPI obtains an inner Galaxy flux of $3.3 \cdot 10^{-4}\,\mathrm{ph\,cm^{-2}s^{-1}}$ (Diehl et al., 2003); this result is derived by fitting the COMPTEL-MEM spatial intensity distribution to finely energy-binned SPI data.

The extended nature of the ^{26}Al emission makes it difficult to employ SPI coded-mask imaging. Therefore, SPI analysis is also performed using simpler "On-Off"-methods, i.e. determining the background level from observations which do not have Galactic ^{26}Al in their FoV, and then subtracting those from the inner-Galaxy measurements (see Diehl et al. (2003); Knödlseder et al. (2004); Diehl et al. (2004)). We aim to clarify in this study to which extent the different sky exposures of source and background may introduce biases to ^{26}Al fluxes deduced using "On-Off"-methods in RHESSI and SPI. Furthermore, we investigate if through intelligent data selections for "On" and "Off" data, we can employ this two-instrument comparison to derive constraints on the possible high-latitude contribution of extended ^{26}Al emission, known to be suppressed in COMPTEL images (Diehl and Timmes, 1998). We report initial steps towards these goals in the present paper.

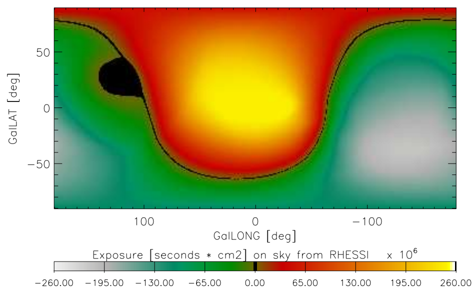


Figure 1. RHESSI sky exposure in D. Smith's analysis (Smith, 2004).

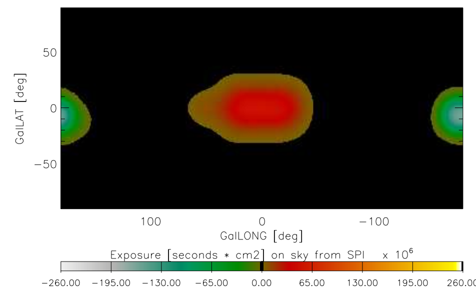


Figure 2. SPI sky exposure for the first two GCDE scans; background: Crab observation (Diehl et al., 2004).

2. RHESSI AND SPI

The INTEGRAL Spectrometer SPI's (Roques et al., 2004) detection plane consists of 19 Ge detectors with a total volume of 3420 cm^3 inside a heavy BGO shield which restricts the Ge camera's FoV to $\sim 30°$ across. SPI can image the sky within this FoV using a coded aperture — SPI model fitting of the ^{26}Al emission uses this imaging capability. 1809 keV emission from the whole galaxy, as well as e.g. the Cygnus and Vela regions, have been addressed (Diehl et al., 2004; Knödlseder et al., 2004; Schanne et al., 2004).

RHESSI is a NASA SMEX solar observatory launched in February 2002 into a 600 km orbit with 38° inclination. Its 9 Ge detectors have a total volume of 2850 cm^3. The main difference compared to SPI is the lack of shielding. RHESSI's Ge detector array views the whole sky at all times — with the exception of the sky region shadowed by Earth ($\sim 130°$ across). Imaging of the sun is achieved with rotating collimators which cover only a small portion of the FoV. RHESSI has been used to measure the ^{26}Al flux from the Galaxy; so far the fluxes published have been calculated on the assumption that all ^{26}Al emission is constrained to $\pm 30°$ in longitude and $\pm 5°$ in latitude.

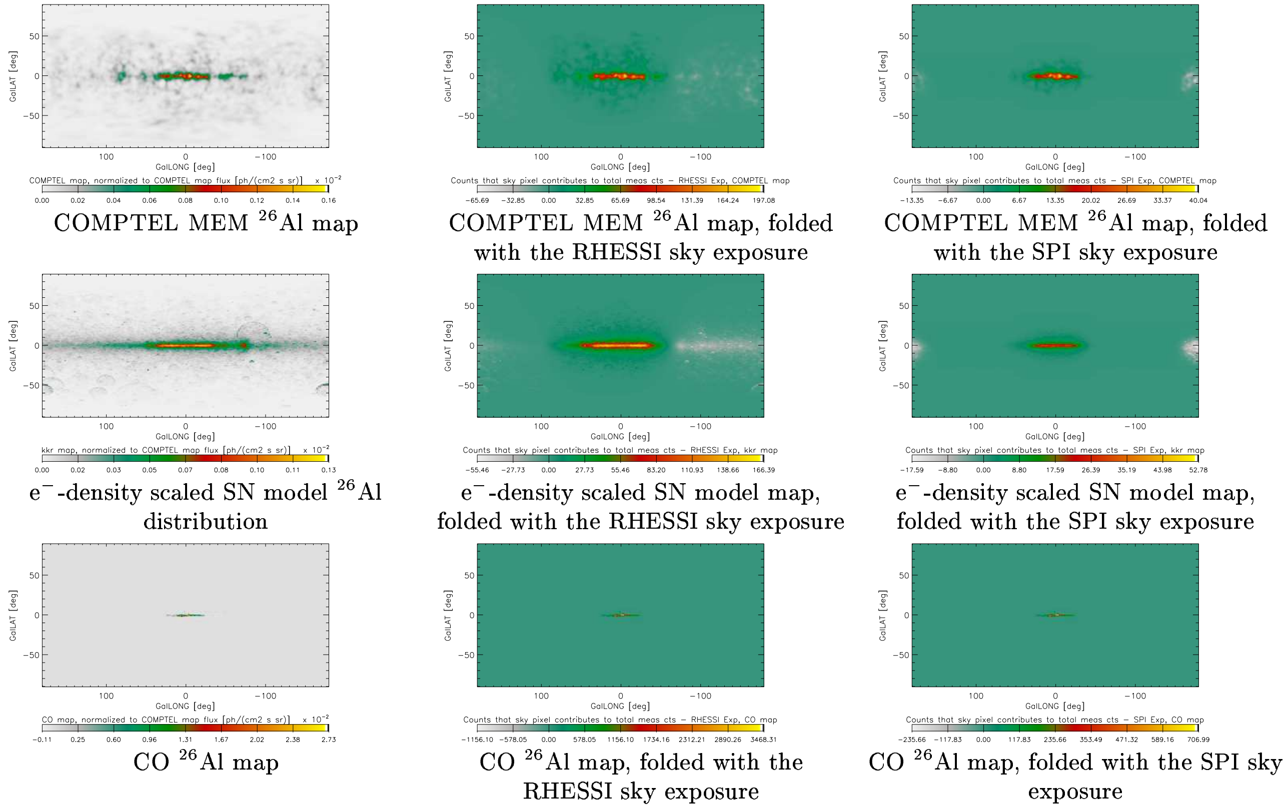
3. THE EXPOSURE MAPS

We have calculated the full-sky exposure for the observations on which the SPI and RHESSI results are based. We give this SPI and RHESSI exposure in units of cm^2s, i.e. 1.8 MeV effective area multiplied with exposure time (Figures 1 and 2).

The RHESSI average effective area for 1.8 MeV photons is 28.6 cm^2 for every incident direction not occulted by Earth (Smith, 2004, varies with angle from 19–34 cm^2, 5% uncertainty). Due to the large sky area viewed at any time, observations used in the background determination also view the Galactic plane outward of $\pm 30°$ longitude. Adding up the GC region measurements ("positive exposure") and the appropriately weighted background ("negative exposure") results in regions of the Galactic plane outward of $\sim 100°$ and $\sim$-60° longitude receiving net negative exposure. Thus, any ^{26}Al emission from these regions would reduce the 1809 keV flux measured by RHESSI. (See Smith, 2004, for measurement and background data selection criteria.)

For SPI, the effective area of the Ge camera (viewed as one Ge detector for the calculation of this exposure map) varies not only with zenith angle (distance of the incident direction from the instrument axis) but also with azimuth angle; this variation is due to the tungsten-alloy mask which covers the FoV defined by the BGO shield almost completely. For the SPI exposure maps presented here, we have used azimuth-averaged effective areas for the different incident zenith angles. The effective areas are taken from the SPI Instrument Response Functions used for SPI image analysis. SPI's azimuth-averaged effective area to 1.8 MeV photons varies from 55 cm^2 ($\theta = 0°$) to 7 cm^2 ($\theta = 23°$). For incident angles $\theta > 23°$, a large fraction of the 1.8 MeV photons is absorbed by the BGO shields, IBIS, and the spacecraft. At this time, no instrument response for these angles is available. We compared two extreme cases — 4.5 cm^2 and 0 cm^2 effective area — for the SPI response at $\theta > 23°$; the resulting predicted SPI ^{26}Al count rates differed by less than 20% for all 1809 keV distributions considered. (The images shown assume 4.5 cm^2.) The background subtraction for the SPI measurement (using either Crab data, as shown here, or an LMC/SN1987a observation) is much "cleaner" in the sense that no Galactic plane regions that might contain significant ^{26}Al emission, at least according to some spatial distribution models, are included in the background measurement.

The exposure maps illustrate that the total flux observed — by RHESSI, but also by SPI if its data is analyzed in a "lightbucket" fashion, disregarding the coded mask imaging, rather than via model fitting — is highly dependent on the extent of the emission region. For RHESSI, extending the emission out to longitudes further away from the GC will have a large impact on the measured flux since that 1809 keV emission will contribute to the background, reducing the ^{26}Al "signal". For SPI, emission of ^{26}Al at higher latitudes is not observed.



COMPTEL MEM ^{26}Al map; COMPTEL MEM ^{26}Al map, folded with the RHESSI sky exposure; COMPTEL MEM ^{26}Al map, folded with the SPI sky exposure

e$^-$-density scaled SN model ^{26}Al distribution; e$^-$-density scaled SN model map, folded with the RHESSI sky exposure; e$^-$-density scaled SN model map, folded with the SPI sky exposure

CO ^{26}Al map; CO ^{26}Al map, folded with the RHESSI sky exposure; CO ^{26}Al map, folded with the SPI sky exposure

Figure 3. Three different model distributions of ^{26}Al are shown, together with the convolution with the SPI and RHESSI exposure maps. The convolved images show counts that each sky pixel contributes to the total number of counts the instrument would measure if the assumed spatial distribution of the 1809 keV emission is real.

4. DIFFERENT "VIEWS" OF ^{26}AL EMISSION FROM OUR GALAXY

To illustrate the combined influence of ^{26}Al spatial distribution and the exposure map on the measured 1809 keV line intensity, we have convolved several distribution models with the SPI and RHESSI exposure maps. Figure 3 shows the results in terms of counts each sky pixel contributes to the total 1809 keV line counts measured by SPI or RHESSI.

We have chosen three possible ^{26}Al distributions for this study: the maximum-entropy map obtained from COMPTEL, a model of supernova (SN) ^{26}Al sources with a space density proportional to that of the galactic free electrons (Kretschmer et al., 2003, 2004), and the distribution of CO in our Galaxy (Dame et al., 1987). We picked these maps because their different spatial extent illustrates what the different instrumental views make of different sky distributions of ^{26}Al: The COMPTEL MEM map is extended in longitude to about $\pm 100°$, with some extent to high latitudes. Kretschmer's model is even more extended in longitude, but more confined in latitude. The CO map shows a flat distribution extending only to moderate longitudes ($\sim \pm 30°$). Convolving these different maps with the exposures of the SPI and RHESSI measurements illustrates the different treatment of regions far from the GC:

For the COMPTEL MEM map, the RHESSI view shows a reasonable reproduction of the high-latitude emission, but the emission from larger longitudes is somewhat suppressed — and especially at longitudes $\lesssim$-70° this emission is being subtracted, since its contribution to the background data exceeds the contribution to the on-Galaxy data. The SPI view, on the other hand, strongly suppresses both higher-latitude emission and emission from farther out in the Galactic plane; conversely, no negative contributions from regions of significant emission in the COMPTEL map are apparent.

For the electron-density scaled SN model ^{26}Al distribution, no significant changes in the latitudinal extent are visible. Especially for the RHESSI observation a strong contribution to the background from Galactic plane regions further away from the GC are evident; these result in a significant reduction of the total measured Galactic flux. In the SPI 'view', the longitudinal extent of the source distribution is much reduced, indicating that only emission from regions close to the GC is contributing to the 1809 keV flux measured by SPI.

For the CO tracer map, no modifications are evident when it is viewed by the two instruments. The emission is confined to regions well exposed by both detector systems.

We have used the results of this study to deter-

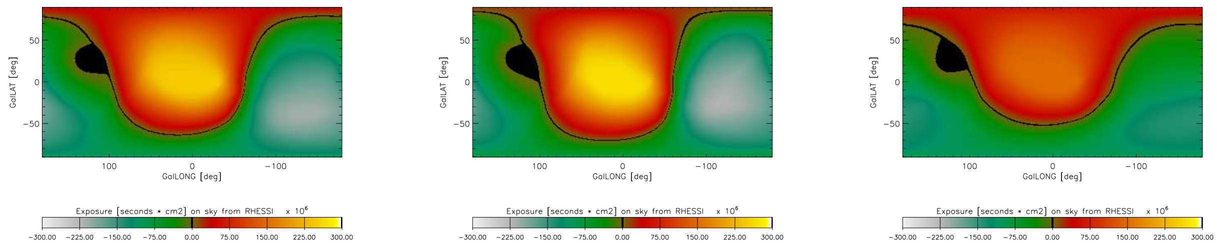


Figure 4. RHESSI sky exposures: as presented in Smith (2004) (left), with emphasis on the left side of the Galaxy (center), and with emphasis on the right side of the Galaxy (right).

mine the "inner Galaxy" ($\pm 30°$ longitude) flux corresponding to the RHESSI flux measurement (Smith, 2004) under the assumption that the COMPTEL MEM spatial distribution is true. This makes the RHESSI numbers, published as "flux calculated under the assumption that all 1809 keV emission originates from inside a box $\pm 30°$ in longitude and $\pm 5°$ in latitude" easier to compare to previous measurements and those of SPI.

COMPTEL (MEM) 1.8 MeV flux from the inner Galaxy is $2.8 \pm 0.15 \cdot 10^{-4}$ ph cm^{-2}s^{-1} (Diehl et al., 2003). Using this distribution as a model, SPI obtains $3.3 \cdot 10^{-4}$ ph cm^{-2}s^{-1} (Diehl et al., 2003). A convolution of the RHESSI inner Galaxy exposure map corresponding to D. Smith's analysis (Smith, 2004) with the same distribution predicts $7.3 \cdot 10^{-3}$ counts/s in the 1809 keV line. RHESSI measures $(10.5 \pm 0.8 \pm 0.4) \cdot 10^{-3}$ counts/s; this would correspond to $(4.05 \pm 0.3 \pm 0.2) \cdot 10^{-4}$ ph cm^{-2}s^{-1} flux in the ^{26}Al line from the inner Galaxy.

5. DISCUSSION AND OUTLOOK

The results of this study clearly indicate that the combination of the instrument exposure map with the model ^{26}Al distribution assumed can have a significant impact on the ^{26}Al flux derived from the measurement.

Comparing the SPI and RHESSI Al-line fluxes assuming the spatial distribution given by the COMPTEL MEM map shows the flux measured by RHESSI to be about 20% higher than that determined by SPI. This is still a preliminary result. Given that there is a 5% uncertainty on the RHESSI average effective area, with additional uncertainty from the zenith angle variation, in addition to the count rate uncertainty, and the uncertainty of the SPI-determined flux given as the span of results from different model fits in Diehl et al. (2003), the SPI and RHESSI ^{26}Al fluxes agree within uncertainties.

Our future efforts will include an attempt to construct a (smaller) RHESSI data set whose exposure map is more concentrated on the GC to allow somewhat more direct comparison to SPI data. Moreover,in parallel to ongoing efforts in SPI data analysis, we will analyze subsets of RHESSI data emphasizing the right and left sides of the Galaxy in an attempt to measure differences in the Al line position/shape due to Galactic rotation (Kretschmer et al., 2004). Preliminary RHESSI exposure maps illustrating this possibility are shown in Figure 4.

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