SEARCH FOR GAMMA RAY EMISSION FROM ^{12}C* AND ^{16}O* DECAYS IN THE GALAXY WITH INTEGRAL/SPI

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ABSTRACT

The study of gamma–ray emission produced in the Galaxy by interactions of cosmic–rays with the interstellar medium is one of the scientific goals of the INTEGRAL mission. We report the status of our preliminary study of gamma–ray lines from ^{12}C* and ^{16}O* decays with the spectrometer INTEGRAL/SPI. We describe the analysis method, an ON and OFF technique, and we highlight our efforts and prospects in background modeling. No detection of ^{12}C* and ^{16}O* decays can be reported yet.

Key words: INTEGRAL/SPI; gamma–rays:observations.

1. INTRODUCTION

The observation of a specific kind of γ–ray lines would sign the interaction of cosmic–rays with the interstellar medium (ISM) (Ramaty et al. [1]). It would provide information (i) on the low energy cosmic–ray component (below 100 MeV); (ii) on the origin of the light elements Li, Be, and B which are supposed to be mainly produced by spallation of heavier nuclei; (iii) on the nature of the interstellar medium. The γ–ray lines expected are those resulting from spallation and/or direct excitation of the most abundant nuclei in the Galaxy like C, N, O, Mg, Si, etc. Those interactions have not yet been detected, but present γ–ray telescopes with a high spectral resolution, such as the INTEGRAL spectrometer SPI, might allow such a detection. In the following we are interested in two of those γ–ray lines, emitted by ^{12}C* and ^{16}O* nuclei at the energies of 4.438 MeV and 6.129 MeV, which have been detected in solar flares. The carbon and oxygen lines are mainly produced by two processes, α–particle or energetic proton inelastic scattering off the nucleus and nuclear spallation by an α–particle or energetic proton (p). The reactions involved are the following (where x stands for p or α):

- $^{12}C(x,x)^{12}C^\star$, $^{16}O(x,x\alpha)^{12}C^\star$
- $^{16}C(x,x)^{16}C^\star$, $^{20}Ne(x,x\alpha)^{16}C^\star$

The γ–ray line shape depends on the nature of the medium where the interactions take place and on the life–time of the excited state of the nuclei considered. Moreover Tatischeff et al. [2] studied the interactions of cosmic–ray protons and α–particles with two different components of the ISM: gas and dust grains. For several nuclei, interactions with the gas would produce a broad line while interactions with the dust would produce a more intense and narrow line. The reason is, that the excited state is relatively long–lived such that the recoiling excited nucleus can stop in solid materials, such as grains, before the γ–ray is emitted. In this context, the 6.129 MeV excited state of the ^{16}O is largely long–lived and the two components of the γ–ray line are clearly separated (see the predicted ^{16}O line shape in figure 1). This is not the case for Carbon; we don't expect the narrow component since the 4.438 MeV state is short lived, such that the recoiling ^{12}C* nuclei mostly de–excite in flight, independently of the nature of the medium (gas or dust grains).

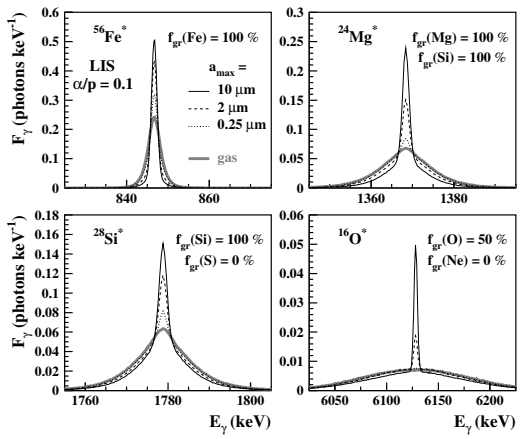

Figure 1. Shape of the γ–ray lines at 847 keV (^{56}Fe), 1369 keV (^{24}Mg*), 1779 keV (^{28}Si*) and 6129 keV (^{16}O*), excited in cosmic–ray proton and α–particle interactions with interstellar gas and dust grains. The calculated spectra are normalized to one photon emitted in each line and convolved with the SPI response function. Thin curves display interactions with dust grains. Thick grey curves display interactions with interstellar gas (from Tatischeff et al. [2])*

2. LIGHT–BUCKET ANALYSIS METHOD

Due to the large count rate from instrumental background (caused by cosmic rays, solar particles and deactivation of the instrument itself), the search for astrophysical γ–ray lines in the SPI data is very difficult. In the whole energy band (20 keV to 8 MeV) strong background lines are present at similar energy as the expected astrophysical lines (Weidenspointner et al. [3]). The method applied here is a so called ON and OFF method for which the main step is a good modeling of the background. In this analysis, we use the SPI spectrometer in a "light–bucket" mode (considering all 17 active Ge detectors as one big detector and ignoring the coded–mask modulation). Data are separated into two sets: typically a Galactic high–latitude "OFF" dataset where no signal is expected and a Galactic low–latitude "ON" dataset where the signal is expected. The OFF data set is used to calibrate a background model in order to estimate the background present in the ON dataset and the residuals over the background model in the ON data is considered as the signal searched for. To construct the background model, information coming from various SPI spectrometer sub–systems are used as tracers. Those include:

- counting rates from the anti–coincidence shield (ACS);
- the plastic scintillator (PSAC) counting rate;
- counting rates of several background lines detected in the Ge camera;
- particle rates measured by the INTEGRAL Radiation Environment Monitor (IREM).

The background model is built from a linear combination of tracers activity fitted to the OFF data. We determine the coefficients w_i in formula 1 where B_p^{OFF} is the background count–rate for the pointing p and $T_{i,p}^{OFF}$ are the tracers considered.

$$B_p^{OFF} = w_0 + \sum_{i=1}^{Ntracers} w_i \times T_{i.p}^{OFF} \qquad (1)$$

The background count rate B_p^{ON} under the count rate measured C_p^{ON} is then predicted using the w_i found and the ON data tracers $T_{i,p}^{ON}$. Finally, the signal searched for S_p is the residual $S_p = C_p^{ON} - B_p^{ON}$

The number of background lines is very large. Most of them are strongly correlated. To avoid biases in the selection of tracers (induced by the difficulty to understanding of the multiple sources of background) we used a Principal Component Analysis (PCA) (Press et al. [4]). It reduces the high dimensional data space corresponding to a large number of variables to a smaller data space and thus number of independent components. The PCA presents the advantage of reducing the number of tracers without an a priori choice of tracer combinations tuned by hand to the signal searched for.

2.1. Test of the method on the 511 keV emission

To check the analysis method we applied it to the 511 keV emission in the Galactic Center region; the detection of this emission is well confirmed by others analysis (for example Knödlseder et al. [5]). We performed the analysis on a set of data including SPI public data collected between July 2004 and June 2006; ON data are taken in the range [-30°;30°] in galactic latitude; outside this latitude range, data are considered as OFF data (see section 3 for details). To build the background model we used the 10 first components of the PCA computed from a set of 70 tracers. Among those 70 tracers, 47 are counting rates from background lines and the others are couting rates from ACS, PSAC and IREM. Residual count rates after background substraction for the OFF and ON dataset are shown in figures 2. In the ON dataset, we see a significant residual signal around the Galactic Center longitude.

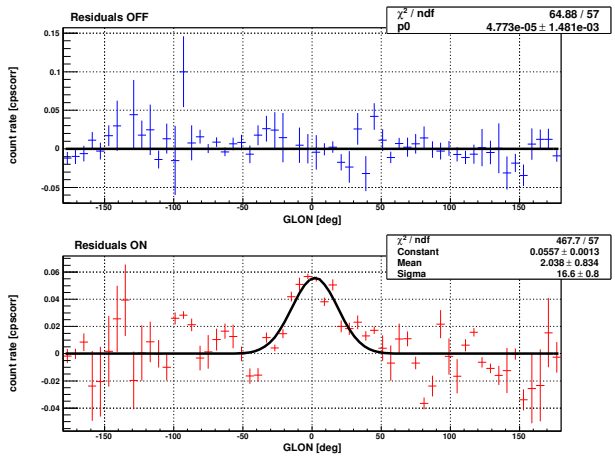

Figure 2. Residual count rate per second (in the 511 keV energy band, 10 keV wide) as a function of the Galactic longitude for the OFF dataset (top panel) and for the ON dataset (bottom panel). We consider the galactic plane data in the range [-30°;30°] in galactic latitude as ON data; outside this low–latitude range, data are considered as OFF data (see section 3). The PCA has been computed from a set of 70 tracers, and to fit the background model we used the 10 first components of the PCA. After background substraction, we see a significant residual signal around the Galactic Center longitude in the ON dataset.

3. DATA

The set of data used for the search of $^{12}C^{\star}$ and $^{16}O^{\star}$ decays concerns all public data collected by the SPI spectrometer since July 2004 (corresponding to revolution 214, failure of the germanium detector 17). Data in the range [-30°;30°] in Galactic latitude are considered as ON data, others are OFF data (the exposure time as a function of the Galactic longitude is indicated in figure 3). Before performing the analysis, the data are cleaned of solar flares and radiation–belt passages.

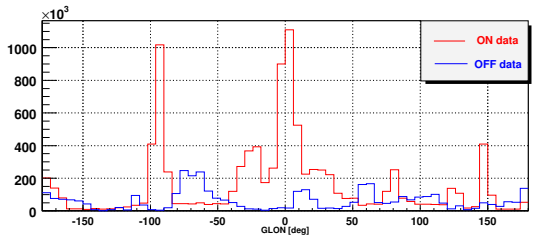

Figure 3. Exposure time (seconds) of ON and OFF datasets as a function of the Galactic longitude.

4. ANALYSIS

We searched for $^{12}C^{\star}$ and $^{16}O^{\star}$ γ–ray emission (4.438 MeV and 6.129 MeV) in the data described above. These two lines are expected to be broadened. For the carbon line, we searched in a large energy band (150 keV) around 4.438 MeV. For the oxygen line, since the prediction indicates several components in the line, we divided the energy range (6054 keV – 6190 keV) into 3 bands (see figure 4). The 6124 keV – 6140 keV tracing the narrow–line and the two others the broad–line component.

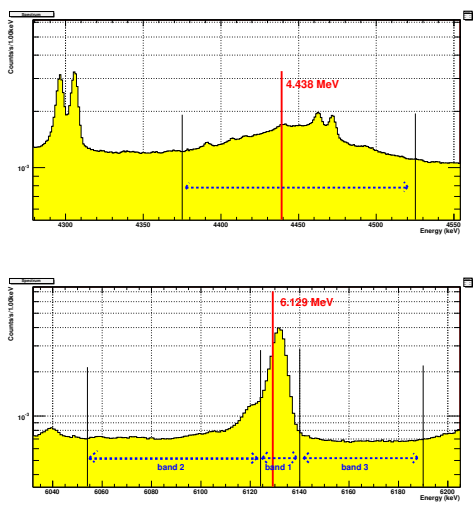

Figure 4. SPI *spectrum at 4.438 MeV and 6.129 MeV*

We performed a light–bucket analysis in different energy bands, one for the carbon and three for the oxygen. To fit the background model we used the 6 first components of the PCA computed from a set of 70 tracers.

4.1. Search for $^{12}C^{\star}$

For the carbon line there is no significant difference between ON and OFF data (see results on figure 5). We conclude that we do not detect any signal at 4.438 MeV originating from the Galaxy in this ON data set.

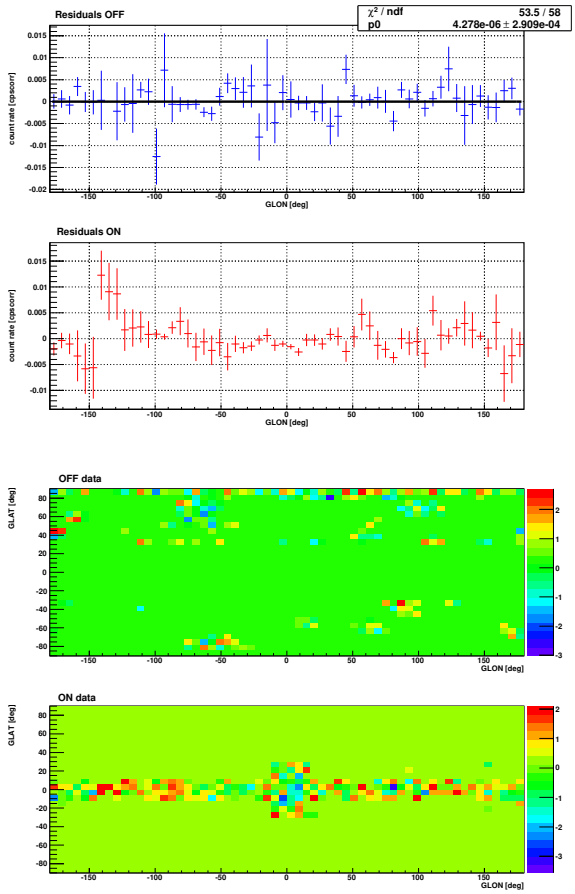

Figure 5. Result for $^{12}C^{\star}$. From top to bottom panel: residual count rate per second for OFF and ON data; excess map in significance (σ) for OFF and ON data; as a function of Galactic longitude. The OFF and ON datasets used are those described in section 3.

4.2. Search for $^{16}O^{\star}$

Results of the oxygen study are shown in figures 6 and 7, for the narrow–line and broad–line component respectively. In both figures, from top to bottom, the four panels indicate the residual count rate per second for OFF data,

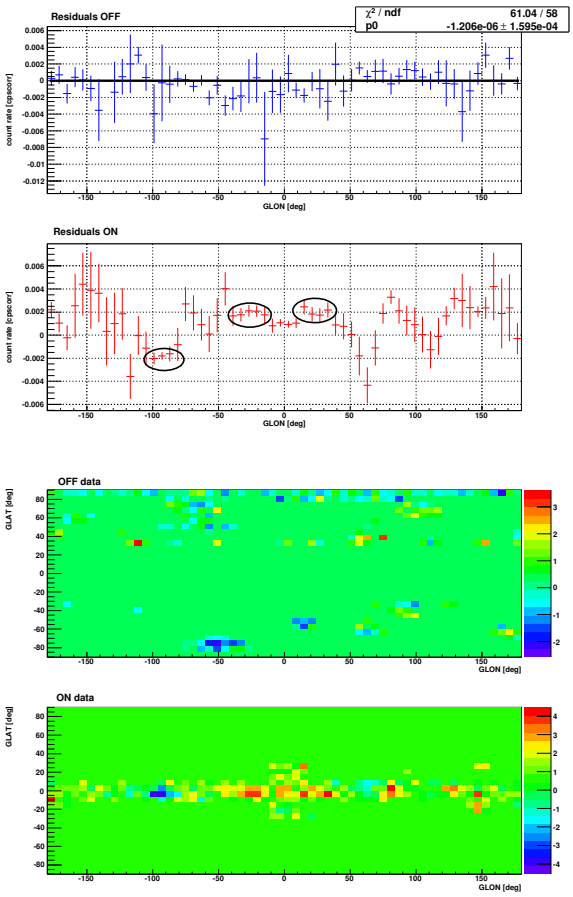

Figure 6. Result for $^{16}O^{\star}$, band 1 (narrow component)

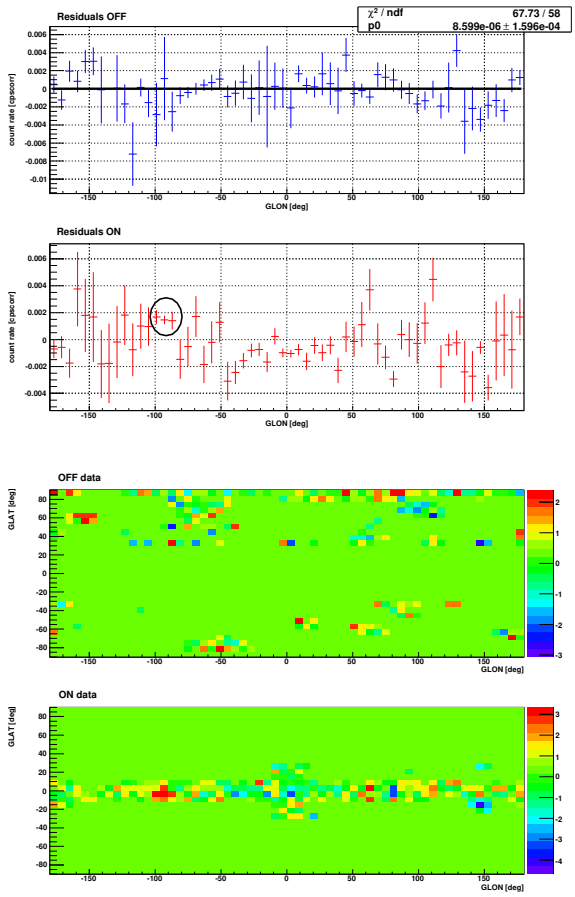

Figure 7. Result for $^{16}O^{\star}$,band 2 (broad component)

ON data; and the excess map in significance (σ) for OFF data, ON data; as a function of Galactic longitude. We notice that structures appear at the limit of the 3σ significance level in the Galactic excess map, notably at -30°, 30° and -100° in Galactic longitude for the narrow ^{16}O line (figure 6) and at -100° in Galactic longitude for the broad ^{16}O line (figure 7). This structures (excess or deficit) correspond to the groups of points marked in the ON residuals (figures 6 and 7). However if we look carefully at the background model residuals, it appears clearly that we still have systematic effects in our background model. Thus it is necessary to study in details the systematic effects by a systematic study of the background subtraction. For example we will have to understand the effects of different tracer combinations, and the consequences of the cut on the number of PCA components kept for the background model. Furthermore, this analysis has been performed only with the single events, the next step is to perform the same analysis with the multiple events. Also the background model could be enhanced if the OFF dataset could be enlarged, this could be achieved by restricting the ON data to the band [-20°;20°] in galactic latitude, and considering the complementary band as OFF data. However, we have to study carefully if no signal is expected to fall into the enlarged OFF dataset.

5. CONCLUSIONS

Our work on the γ–ray lines beyond 2 MeV with SPI is in progress; the analysis presented here is a very preliminary and qualitative study using a limited set of data. In addition to the investigation of the systematic effects, which needs to be performed, we need to extend the analysis to the other existing data sets (sets of data before the failure of Ge detector 17, future public data). This will improve the understanding and the precision of our background model. It will also permit to confirm or infirm the presence of structures seen in the Galactic excess map for the ^{16}O line.

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