

RHESSI results on gamma-ray lines from diffuse radioactivity

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Abstract

Although designed to study solar flares, the *Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)*, a NASA satellite, has proven to be sensitive to gamma-ray lines generated by recently-created radionuclei in the inner Galaxy. I present the current state of this investigation, including flux and line shape measurements of the 1809 keV line from ²⁶Al and a preliminary detection of the lines of ⁶⁰Fe.

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1 Introduction

The *Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)*, which was launched on February 5, 2002, is part of NASA's Small Explorer series of satellites (Lin et al., 2002). *RHESSI* was designed to perform imaging and spectroscopy of solar flares in the hard x-ray and gamma-ray range, with both spatial and spectral resolution far superior to previous missions. It uses Rotating Modulation Collimators (RMCs) for solar imaging down to 2.3" (Hurford et al., 2002). Its nine coaxial germanium detectors cover the range from 3 keV to 17 MeV with extremely good energy resolution ($E/\Delta E$ around 400 from 1–2 MeV) (Smith et al., 2002). Figure 1 shows the position of the detectors within the spacecraft. Each detector is segmented into a thin front segment (which records the copious hard x-ray photons coming down the spacecraft axis from a solar flare) and a thick rear segment (built to observe solar gamma-rays at higher energies which penetrate the front segment).

Because these detectors have no shielding, and because the spacecraft is very light, the *RHESSI* detectors can see emission at gamma-ray energies from any

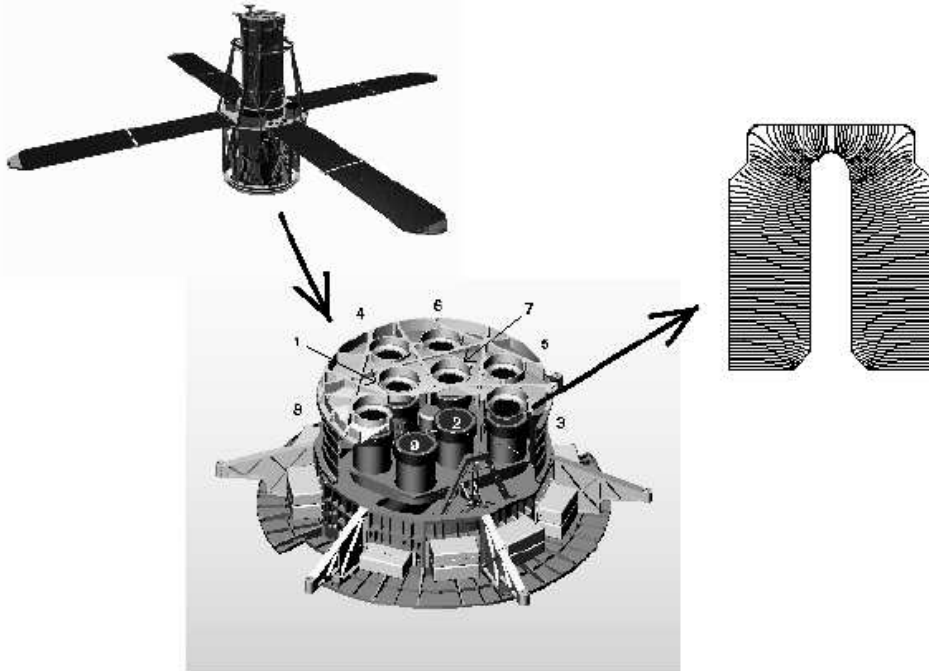


Fig. 1. The *RHESSI* spacecraft (left), with an expanded view of the spectrometer (center) and a cross-section of a single germanium detector (right). The detector picture shows electric field lines in the crystal. The electric field line which separates the front and rear segments runs approximately from the point where the outer radius starts to widen to a point several millimeters below the top of the inner bore. The front and rear segments, although part of the same crystal, are read out separately.

direction in the sky. For photons on the order of 1 MeV or higher, in fact, the instrument's effective area (about 20 cm^2 at 1809 keV) is virtually independent of the direction of incidence. This allows the spectrum of emission from the inner Galaxy to be derived by using the Earth as an occulter, subtracting data taken when the inner Galaxy is occulted from data taken when it is visible, in order to eliminate instrumental background.

The significance of the gamma-ray lines from the decay of recently-synthesized Galactic ^{26}Al and ^{60}Fe are discussed at length elsewhere in this volume. Briefly, they are of particular interest because their half-lives (both on the order of a million years) are short enough that their distribution on the sky is representative of the *current* state of ongoing Galactic nucleosynthesis, yet long enough that the distribution consists of a large number of sources (e.g. supernovae, novae, etc.), so that the map of the lines on the sky will have the same shape

as the distribution of the parent sources. For a short-lived isotope like ^{44}Ti , the map is expected to be dominated by a small number of very recent events.

Far more information can be gained by comparing the distributions of the two isotopes than by examining each alone (for a more detailed discussion see Diehl (2003)). They are thought to have some primary sources in common, for example type II supernovae (SNII), modeled in depth by Timmes et al. (1995) (which also includes an excellent bibliography of early work in this field). The other likely source for ^{26}Al from young stars is the winds from Wolf-Rayet stars, which are not, however, thought to produce much ^{60}Fe before they explode (e.g. Arnould, Paulus, & Meynet (1997)). Older stellar populations can contribute to ^{26}Al via novae and the winds of asymptotic giant branch stars, but the maps of ^{26}Al made by Comptel indicate that young stars dominate the formation of that isotope (Prantzos & Diehl, 1996).

The two results I discuss here are a measurement (Smith, 2003) of the intrinsic width of the ^{26}Al line at 1809 keV (which can be broadened by Galactic rotation and by any birth velocity of the young material, e.g. from a supernova explosion) and a tentative first detection of the lines from ^{60}Fe at 1173 keV and 1332 keV.

2 Analysis Technique

I summed *RHESSI* data into spectra integrated over 1 minute, using only the thick rear segment of each detector (which contains most of the active volume). This integration averages out the effect of the spacecraft's rotation at 15 rpm. The "inner Galaxy" is defined as covering $\pm 30^\circ$ in Galactic longitude and $\pm 5^\circ$ in Galactic latitude. When *none* of this region is occulted by the Earth, each minute of data is summed into the total "source" spectrum, and when *all* of it is occulted, the spectrum is used to create a database of background spectra. Similar background subtraction techniques have been used for observations with the *Solar Maximum Mission* Gamma-Ray Spectrometer (Harris et al., 1990; Harris, Share, & Leising, 1994) and the Burst And Transient Source Experiment on the *Compton Gamma-Ray Observatory* (Smith et al., 1996a,b).

The background database consists of spectra sorted by two orbital parameters: the longitude of the ascending node of the orbit and the orbital phase since the last ascending node. Like geomagnetic coordinates, these parameters predict the cosmic ray flux at the spacecraft well. In addition, however, they also contain information on the history of the passages of the spacecraft through the inner edge of the radiation belts at the South Atlantic Anomaly (SAA). Thus a background spectrum and source spectrum that share common values of these two parameters will have similar fluxes in both those background lines

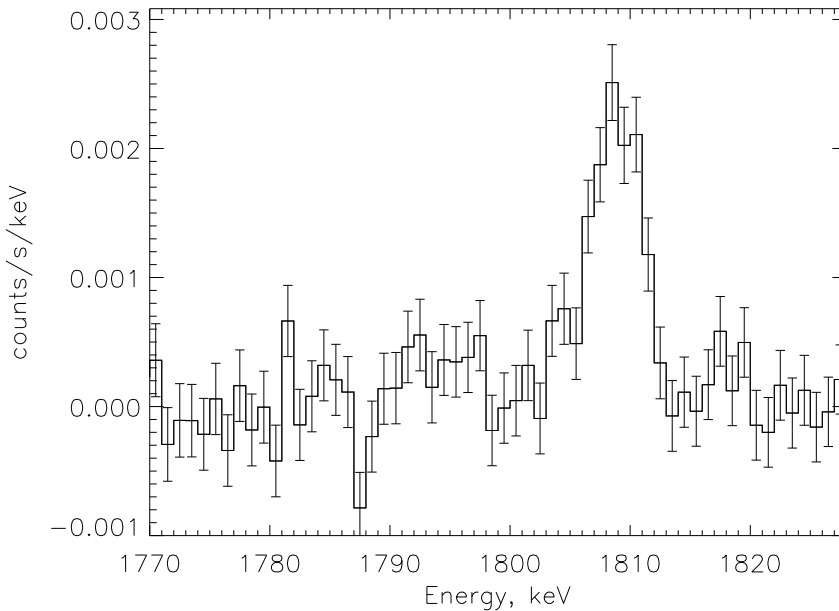


Fig. 2. *RHESSI* measurement of the Galactic 1809 keV line.

that are induced by cosmic rays and emitted at delays of seconds or less and those lines that are induced by trapped protons in the radiation belts and have delays of minutes to hours. Lines from isotopes with decay times of months or years are poorly modeled since they build up over the course of the mission. I have subtracted spectra taken at the beginning of the mission from spectra taken recently to find the long-term radioactivities. From this analysis, it is clear that no such background lines appear at the energies of the ^{26}Al and ^{60}Fe lines.

For each 1-minute source spectrum, I interpolated within the background database to create a customized background spectrum. For the ^{26}Al result, the first nine months of data from the mission were used; for ^{60}Fe , the first fourteen months. When all the spectra have been eliminated for which the inner Galaxy is fully or partially occulted or for which the spacecraft is in the SAA or in some other high-background situation, approximately 25% of the mission elapsed time is actually accumulated into the Galactic spectrum.

3 ^{26}Al Result

The flux and width of the 1809 keV line have been previously presented (Smith, 2003). The flux derived assuming a point source at the Galactic center is $(5.71 \pm 0.54) \times 10^{-4} \text{ ph cm}^{-2} \text{ s}^{-1}$, comparable to the value found by the GRIS balloon (Naya et al., 1996) but significantly higher than the sum of the Comp-

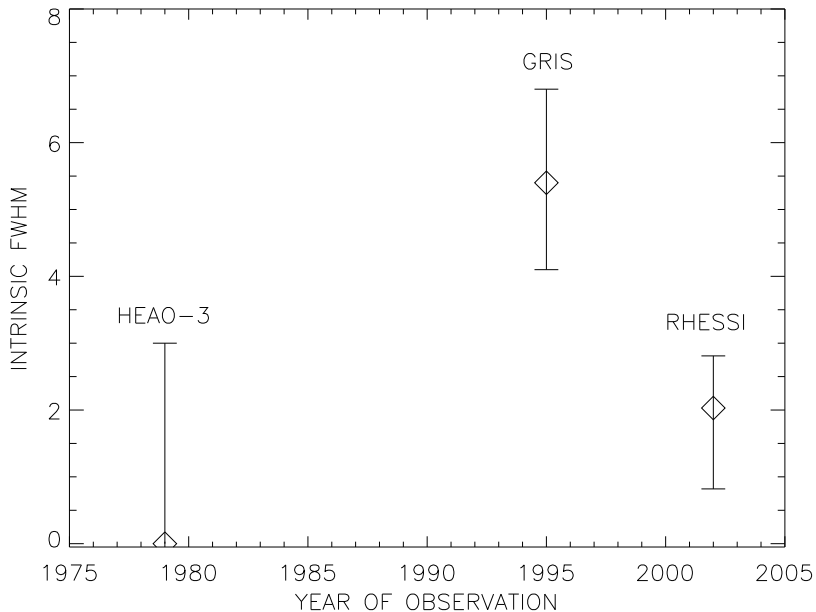


Fig. 3. Three measurements of the width of the Galactic 1809 keV line: HEAO-3 (Mahoney et al., 1984), GRIS (Naya et al., 1996), and *RHESSI* (Smith, 2003).

tel map in this range of Galactic longitude (Diehl et al., 1995). The extension of the real emission will have two effects on our result (Figure 2): emission outside our “inner Galaxy” box will sometimes appear in the source spectra and raise the flux, but it will also sometimes appear in our background spectra and contribute negatively. Convolution of the *RHESSI* response during each minute-long spectrum with model spatial distributions will give a clearer picture of the consistency of the *RHESSI* flux with the Comptel and *INTEGRAL* maps. If it remains significantly higher, we will have to consider the possibility of a very diffuse, large-scale component to the distribution, to which Comptel and *INTEGRAL* would not be sensitive due to their imaging techniques.

Although many observations have been made of the 1809 keV line with germanium instruments, only three have been sensitive enough to put a meaningful constraint on the line width: the original detection of the line by HEAO-3 (Mahoney et al., 1984), an observation by GRIS (Naya et al., 1996), and this work. As can be seen in Figure 3, the GRIS result is inconsistent with the other two, requiring a highly broadened line, much wider than could be explained by Galactic rotation. Since both supernova ejecta and stellar winds are expected to come to rest in the interstellar medium in much less time than the isotope half-life, this has been a subject of much theoretical work on the behavior of ^{26}Al concentrated in grains (Chen et al., 1997; Ellison, Drury, & Meyer, 1997; Lingenfelter, Ramaty & Kozlovsky, 1998; Sturmer & Naya, 1999). The *RHESSI* width is marginally consistent with the expectation from Galactic rotation, but fits slightly better to a broader shape, e.g. one allowing

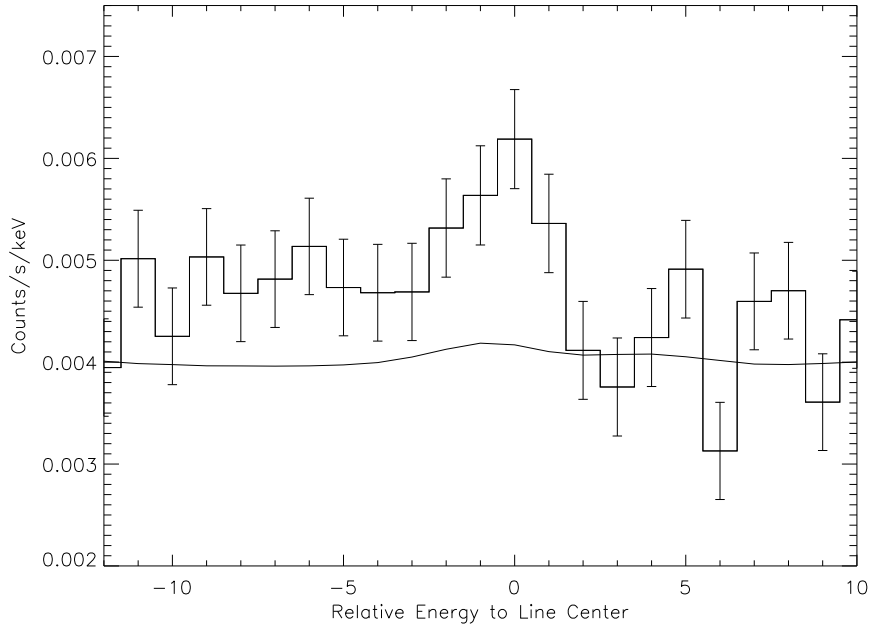


Fig. 4. *RHESSI* co-added spectrum of the two lines of ^{60}Fe . The smooth curve is 0.8% of the background.

a contribution from some fraction of young, fast material (Kretschmer, Diehl, and Hartmann, 2003).

4 ^{60}Fe Result

The ^{60}Fe lines from the inner Galaxy have been predicted to be approximately 16% of the flux of the ^{26}Al line if both are produced by SNII (Timmes et al., 1995), putting the Fe lines right on the edge of detectability for previous missions. With the most statistically significant observation of the ^{26}Al line to date (Figure 2), *RHESSI* might be expected to have the best chance of observing these lines.

This analysis is still in progress, but the results look promising. To maximize sensitivity, I sum together both lines, so that the energy scale is relative to line center. Since both lines have a branching ratio of 100%, are not far apart in energy, and would be expected to share any Doppler shifts and broadening, this approach is justified. The background lines at the same energies as the Galactic ^{60}Fe lines come from isotopes with halflives of minutes, in contrast to the 1809 keV background line, which comes from $^{26}\text{Na}/^{26}\text{Mg}$, which decays in about a second (Weidenspointner et al., 2002). Decay of freshly created nuclei from the SAA proton exposure could therefore create larger, more variable background for the ^{60}Fe measurement, so I exclude orbits following SAA

exposure in this case.

The co-added spectrum of the two lines is shown in Figure 4. The individual lines give roughly comparable flux when fit separately, although the statistics in both cases are, of course, poor. The flux and error values will appear in a paper currently in preparation, which will use somewhat more data. For the 14 months of data used for Figure 4, the significance is slightly greater than 3σ when including a contribution from systematic uncertainties in the background subtraction. The smooth curve in Figure 4 represents 0.8% of the background level, which is approximately the level of systematic uncertainty in the subtraction, based on a survey of other background lines.

The signal has approximately 16% of the 1809 keV flux (for each ^{60}Fe line). This number happens to be identical to the ratio predicted by Timmes et al. (1995), although both the data and modeling have large uncertainties. If there are contributions to Galactic ^{26}Al from objects (not SNII) that do not make ^{60}Fe , then the *RHESSI* result shows either that those contributions are small or that the ratio $^{60}\text{Fe}/^{26}\text{Al}$ for SNII is somewhat higher than predicted.

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