TOWARDS A MEASUREMENT OF THE GALACTIC ^{60}Fe LINES WITH SPI

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Principles of the SPI measurement

Data taken during the first year or so (orbits 19–130, 3.0 days per orbit). All 19 Ge detectors functioned, but resolution varied somewhat, since cosmic rays degraded them and they were periodically restored to full power by annealing. At the energies of the ^{60}Fe lines (1173keV, 1333 keV) the resolution was $\sim$ 2.4–3 keV FWHM. Both single-detector and multiple-detector events were used (but separately, since the energy resolution is poorer for the multiples).

The basic principle is to model the time series of background count rates in each energy bin (1 keV) and then fit this model plus the expected cosmic ^{60}Fe signal to the count rate for each SPI pointing/detector combination. The amplitude of the "signal" parameter returned by the fit yields the ^{60}Fe source flux.

Problems with this approach:

(1) It requires an assumed sky distribution of ^{60}Fe, which is convolved with the instrument response for that pointing to give the signal parameter. We chose to use the *COBE*/DIRBE 240μm all-sky map, because it traces regions of massive star formation and fits the ^{26}Al map well.

(2) The variable energy resolution might cause different energy bins to be included in the lines in different pointings.

(3) Where the map has little or no flux ("off"-pointings) the errors are included in the final fit error.

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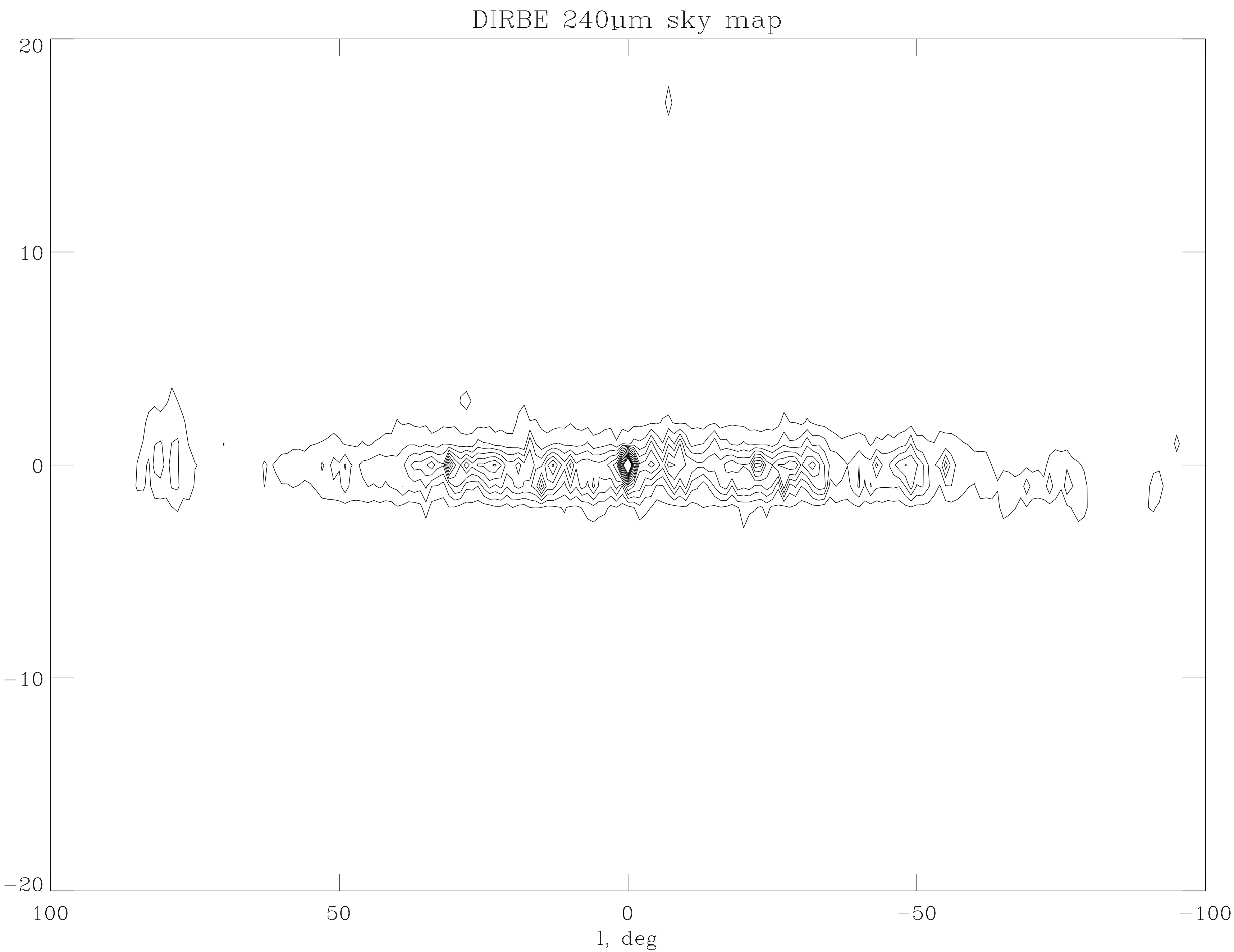

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The background model is less of a problem, since previous SPI analysis has shown that prompt backgrounds (cosmic ray impacts etc.) are well modeled by the count rate in the Ge detectors when saturated (jargon: GEDSAT). The radioactivities produced by these impacts decay with known $\tau_{1/2}$, the most serious being ^{60}Co ($\tau_{1/2} = 5.3$ yr). The obvious model for this is the parent time series (GEDSAT) convolved with an exponential increase on this time-scale as the ^{60}Co approaches equilibrium (jargon: GEDSAT$\otimes^{60}$Co).

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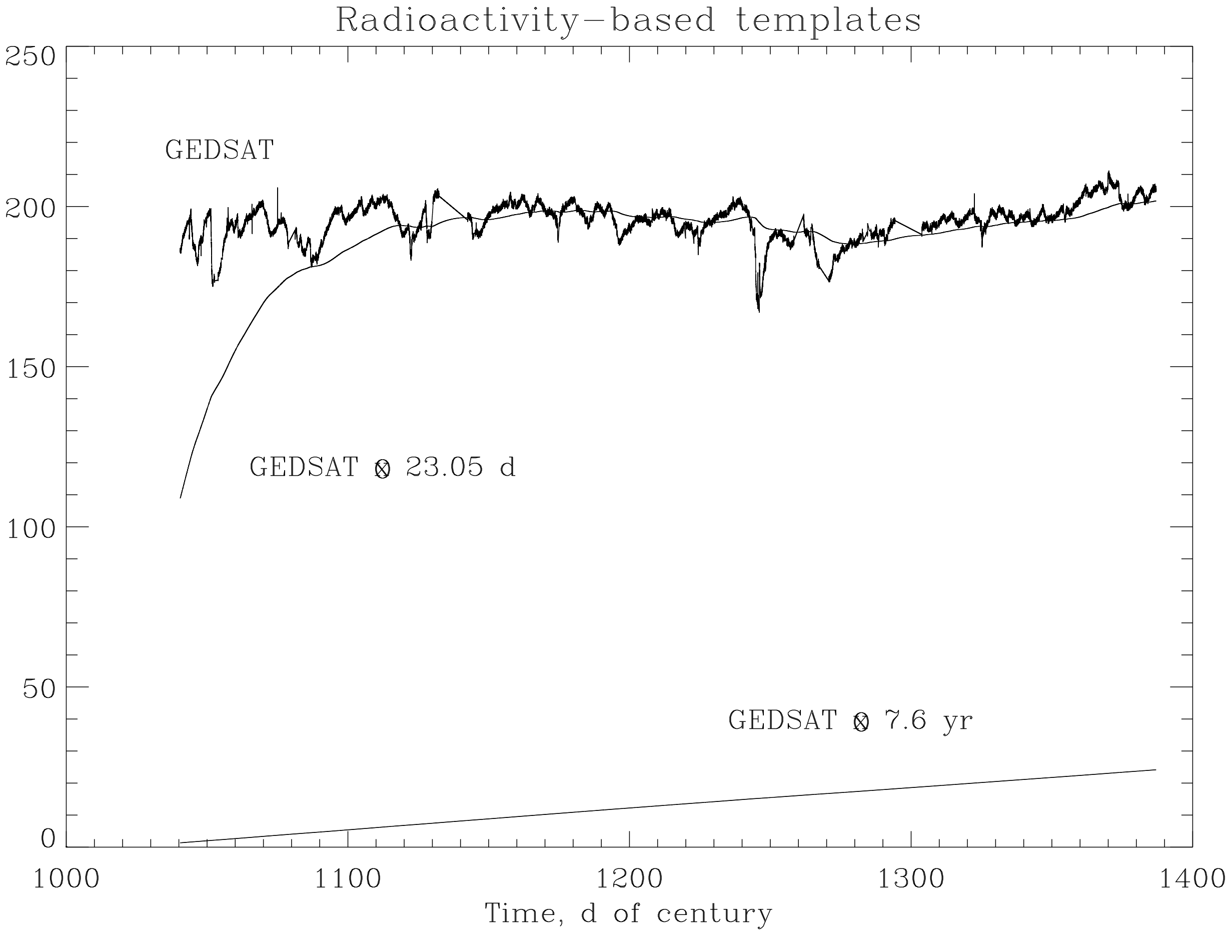

Radioactivity−based templates
GEDSAT
GEDSAT ⊗ 23.05 d
GEDSAT ⊗ 7.6 yr
0
50
100
150
200
250
1000
1100
1200
1300
1400
Time, d of century

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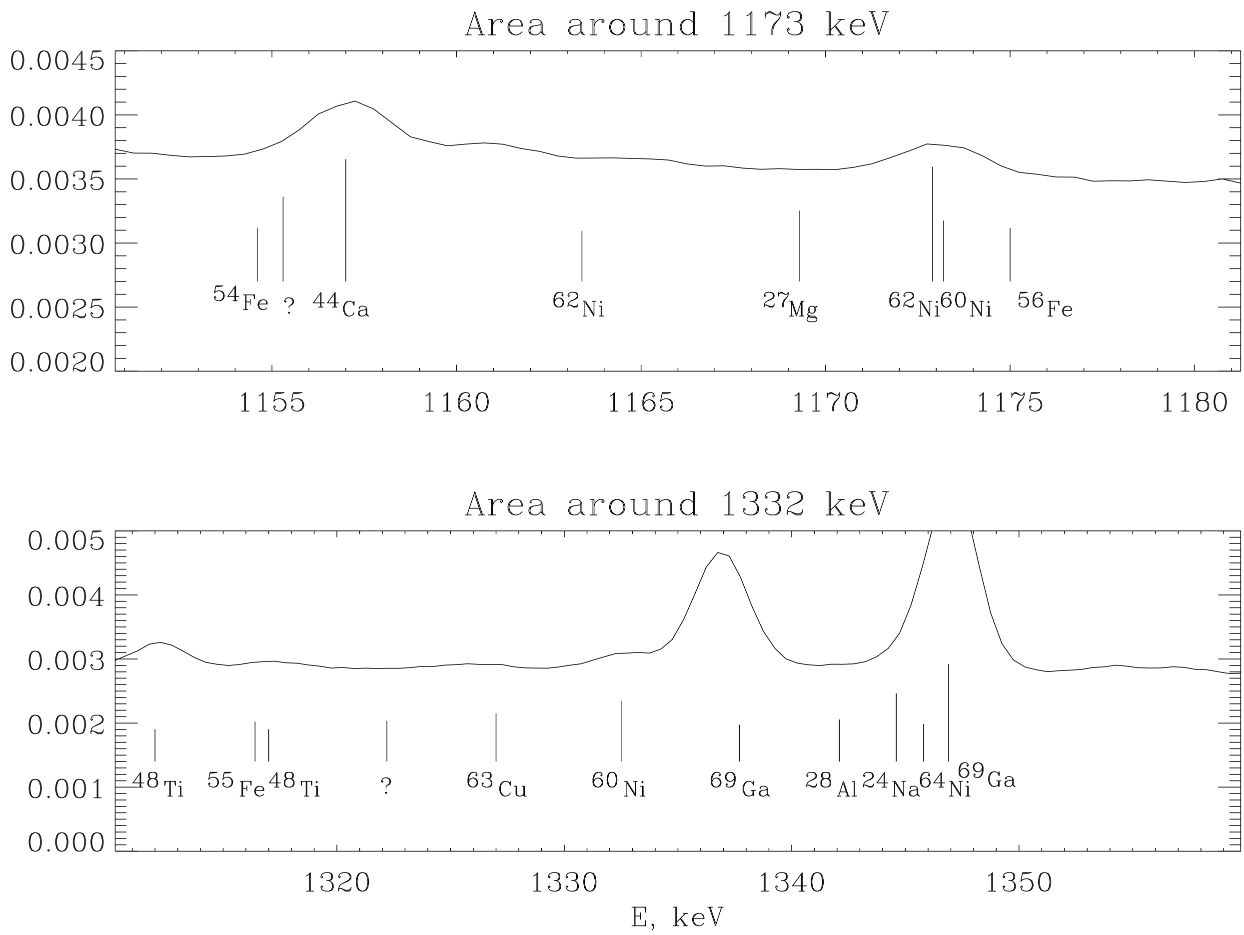

Area around 1173 keV
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
54Fe
?
44Ca
62Ni
27Mg
62Ni
60Ni
56Fe
1155
1160
1165
1170
1175
1180
Area around 1332 keV
0.005
0.004
0.003
0.002
0.001
0.000
48Ti
55Fe
48Ti
?
63Cu
60Ni
69Ga
28Al
24Na
64Ni
69Ga
1320
1330
1340
1350
E, keV

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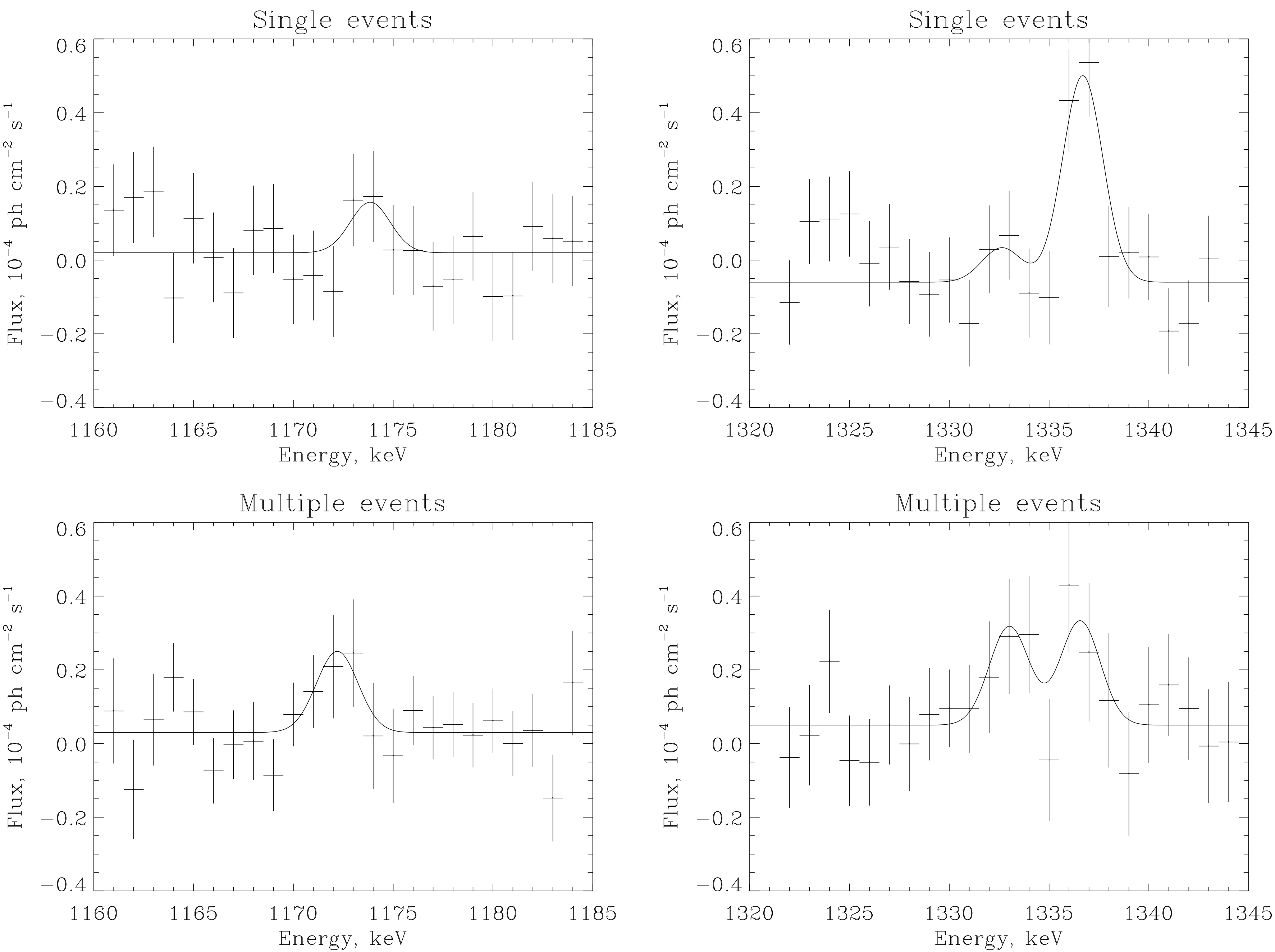
^{60}Fe RESULTS



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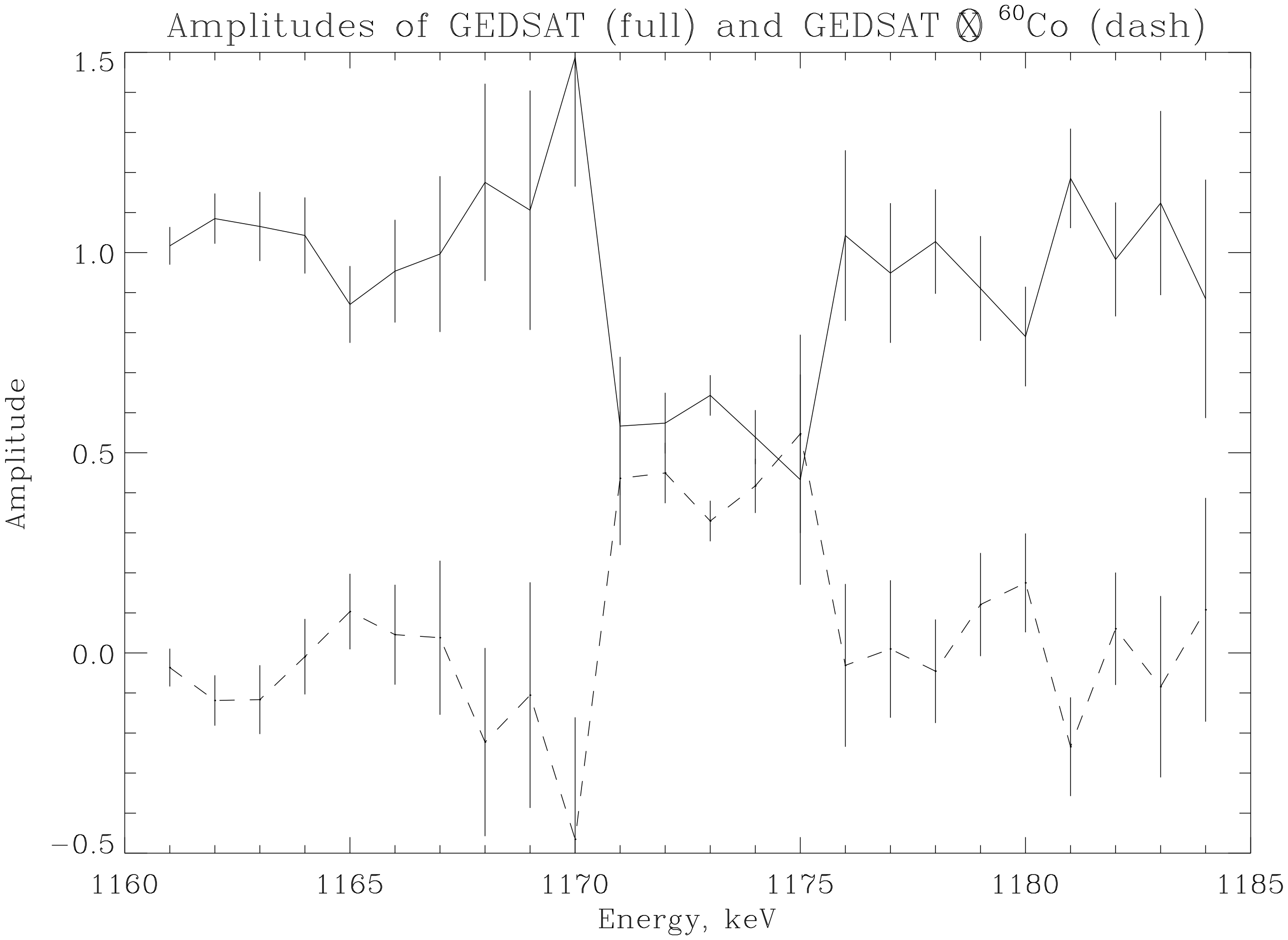
Amplitudes of GEDSAT (full) and GEDSAT ⊗ 60Co (dash)
Amplitude
Energy, keV
1.5
1.0
0.5
0.0
−0.5
1160
1165
1170
1175
1180
1185

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The problem of varying energy resolution

As we saw, during the period of our data the SPI energy resolution was continually degraded by cosmic ray hits and revived by annealing. We kept track of these changes and attempted to correct for them.

We used the OFF-pointing data, from which no ^{60}Fe is expected, for this. We define OFF as being $|b| > 20°$.

The correction procedure mimics the effect of degradation by adjusting the energy of each event by a down-shift $E \to E'$ and a broadening ΔE according to a random number drawn from the probability distribution

$$p(E, E') = \frac{1}{\Delta E} e^{-(E-E')/\Delta E} \quad (1)$$

We fit the OFF data by a combination of the tracers (i.e. GEDSAT, GEDSAT$\otimes^{60}$Co and others) without the map component. This best combination became the background model for the ON data, this time fitted together with the signal component from the sky map. We applied the energy resolution correction to this "best combined tracer" background model before using it with the ON data.

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The bad news. The background model performs poorly at predicting the ON background....see diagram.

The good news. (1) The systematics can be corrected for at the cost of adding to the error (e.g. the ^{62}Ni lines in the diagram).

(2) We can measure the background line widths after the correction.

(3) Best of all, if we fix the line widths at the value measured after correction (typically ~ 2.4 keV FWHM) the correction turns out to make little difference.

Our previous analysis, which did not use the correction, should therefore be unaffected if we fix the line widths correctly.

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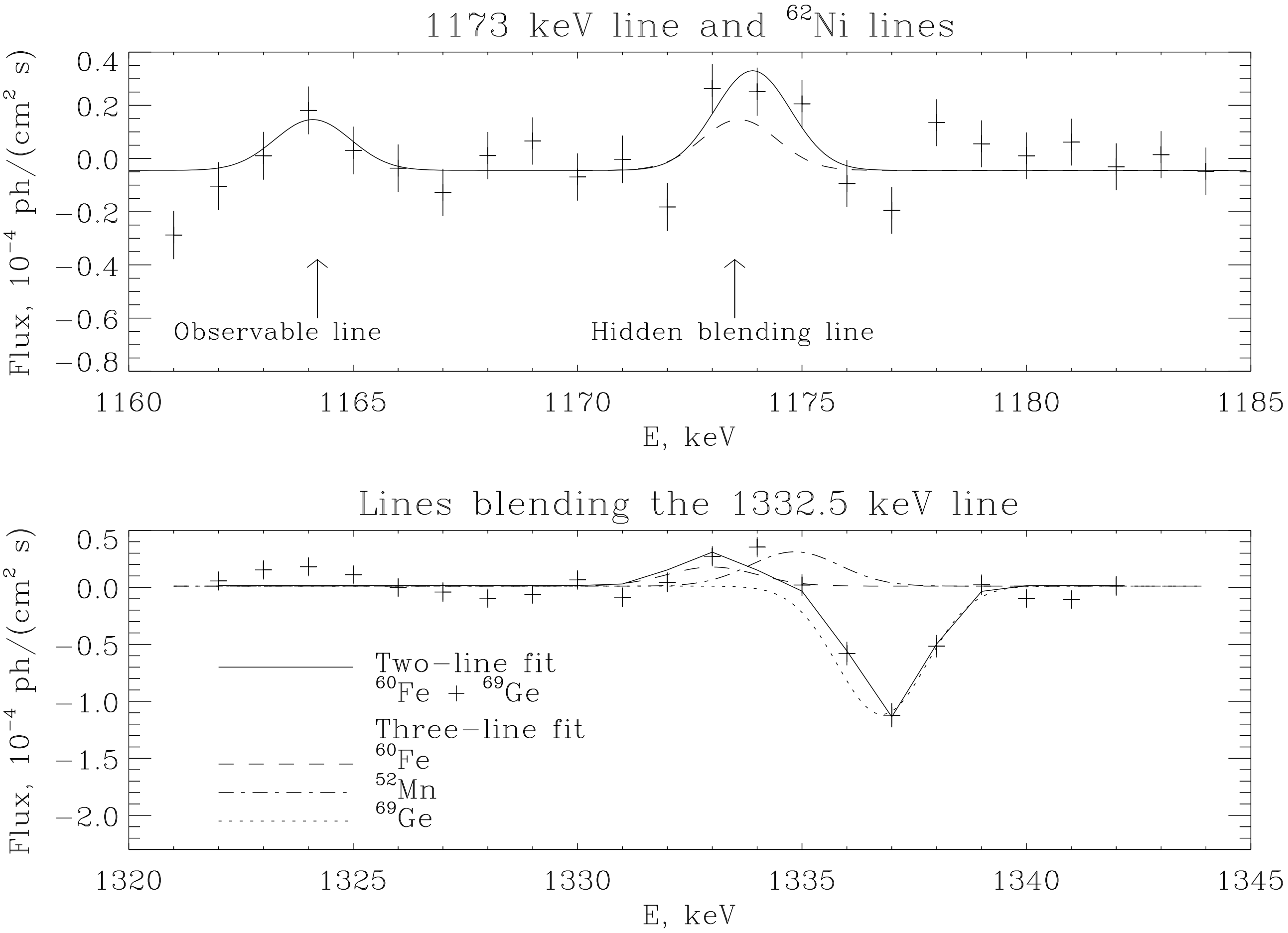

1173 keV line and ^{62}Ni lines
Flux, 10^{-4} ph/(cm^2 s)
Observable line
Hidden blending line
E, keV
Lines blending the 1332.5 keV line
Flux, 10^{-4} ph/(cm^2 s)
Two-line fit
^{60}Fe + ^{69}Ge
Three-line fit
^{60}Fe
^{52}Mn
^{69}Ge
E, keV

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^{26}Al

Returning to the earlier analysis, (i.e. fitting the tracer GEDSAT and the ^{60}Fe signal from the map to all pointings and detectors simultaneously), we can do exactly the same for the ^{26}Al line at 1809 keV.

This may not be the best way of measuring the ^{26}Al abundance and distribution, but any systematic errors in our ^{60}Fe result should cancel out when we divide ^{60}Fe/^{26}Al.

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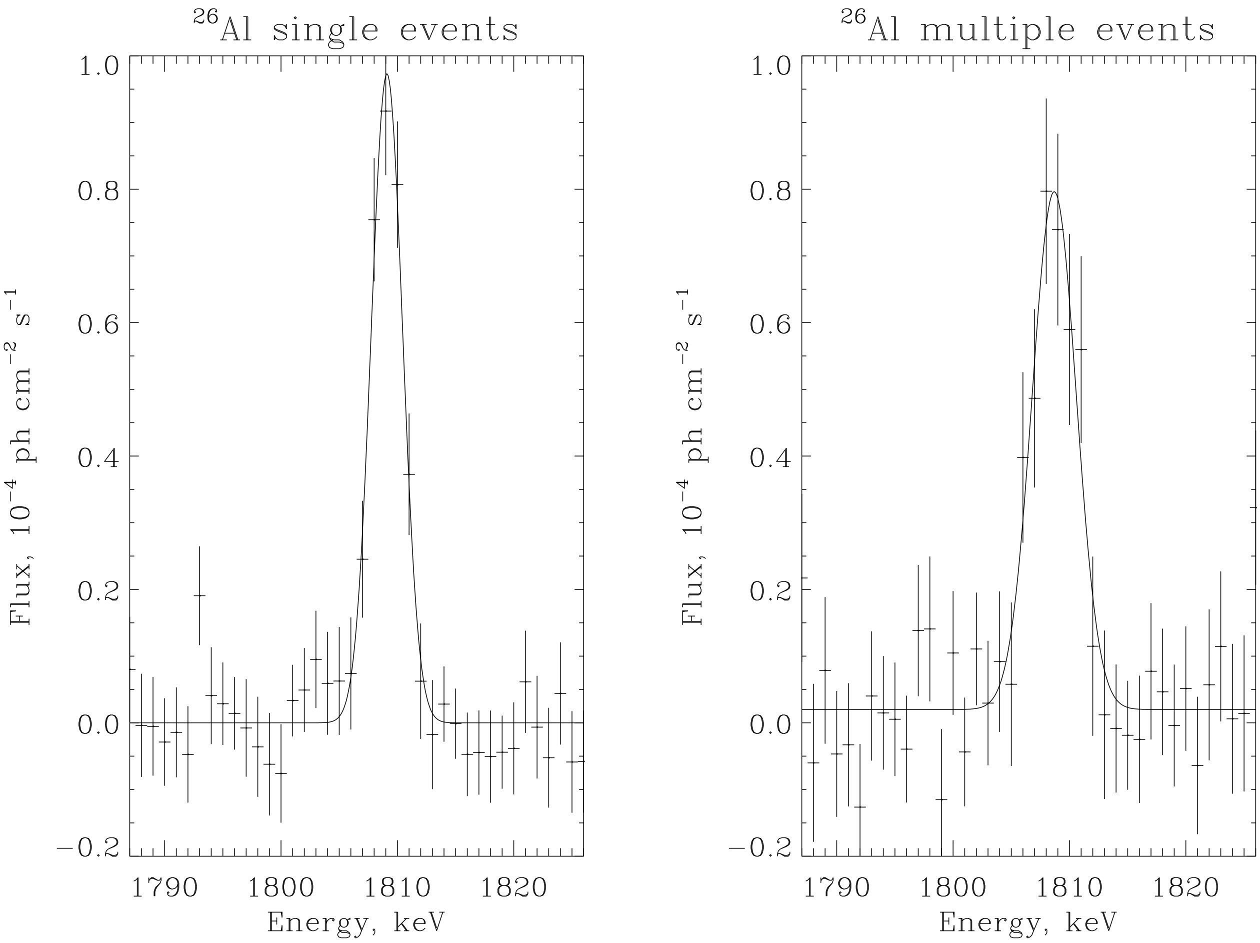

26Al single events
26Al multiple events
Flux, 10-4 ph cm-2 s-1
Energy, keV
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
1790
1800
1810
1820

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RESULTS

The two ^{60}Fe lines are in branching ratio 1:1. We thus get the mean flux per line from 4 independent measurements (two event types, sigle and multiple, for each of two lines):

$\underline{\text{Flux} = 0.37 \pm 0.11 \times 10^{-4} \text{ ph cm}^{-2} \text{ s}^{-1}}$

Any systematic due to the variability of SPI's energy resolution is small ($< 0.30 \times 10^{-4}$ ph cm^{-2} s^{-1}).

The result from the ON/OFF analysis method suffers from much worse systematics and should NOT be used:

$0.40 \pm 0.11(stat.) \pm 0.07(syst.) \times 10^{-4}$ ph cm^{-2} s^{-1}.

Compare *RHESSI*'s result at the 5th *INTEGRAL* Workshop:

$0.36 \pm 0.14 \times 10^{-4}$ ph cm^{-2} s^{-1}.

Our result for ^{26}Al using the same analysis:

$\underline{\text{Flux} = 3.4 \pm 0.2 \times 10^{-4} \text{ ph cm}^{-2} \text{ s}^{-1}}$

giving a single line flux ratio $^{60}\text{Fe}/^{26}\text{Al} = 0.11 \pm 0.03$.

The corresponding number ratio (from $dN/dt = \lambda N$, $\lambda = \ln 2/\tau_{1/2}$) is

$^{60}\text{Fe}/^{26}\text{Al} = 0.23 \pm 0.08$ (including the errors on the $\tau_{1/2}$.)

Therefore, although WR stars are only a few percent of the massive OB population which goes on to core collapse SN, they dominate the ^{26}Al production by 4:1 over all other types.

This picture may change if other sources of ^{26}Al and ^{60}Fe are discovered. Novae might produce up to 10% of ^{26}Al, likewise AGB stars. Delayed-detonation SNIa models predict at least 50% as much ^{60}Fe per event as SNII.

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