PROSPECTS FOR OBSERVING SUPERNOVA PRODUCTS FROM CAS A AND THE VELA REGION WITH SPI

A. W. Strong, R.Diehl, R. Georgii, A.F. Iyudin, and V. Schönfelder

Max-Planck-Institut für extraterrestrische Physik, 85741 Garching, Germany

ABSTRACT

The study of gamma-ray line afterglows from supernova radioactivities is a major objective for the SPI Spectrometer on INTEGRAL. The decay lines of ^{44}Ti and ^{26}Al are the main candidates. We discuss prospects for observing two SNR with observation times similar to those available in the core program. Since the lines are expected to be Doppler broadened, we study the effect of line-width on the detectability of SNR.

Key words: gamma rays; supernova remnants; nucleosynthesis; INTEGRAL spectrometer.

INTRODUCTION

Young supernova remnants (SNR) contain freshly synthesized heavy elements, of which some of the long-lived radioactive species are visible in gamma-ray lines. A prime objective of the spectrometer SPI on INTEGRAL is the study of the ^{26}Al and ^{44}Ti lines predicted by nucleosynthesis models of supernovae. Both lines have been detected (see review by Diehl & Timmes 1998). While for the ^{26}Al mapped throughout the Galaxy the contribution of supernovae is uncertain (see review by Prantzos & Diehl 1996), the ^{44}Ti detection from the 300-year-old Cas A supernova remnant with COMPTEL (Iyudin et al., 1994) directly supports a core-collapse supernova origin for this isotope. Cas A will be a prime target on account of the COMPTEL detection of ^{44}Ti emission. Extended ^{26}Al from the Vela region has been detected by COMPTEL, suggesting that superposition from many sources makes up the emission in this region (Diehl et al., 1999). But this region also includes several specific and nearby candidate sources of radioactivity. On these grounds the Vela region was selected as an INTEGRAL Core Program Category III target. Therefore a study of the prospects and required observation strategy for these targets has been started. Preliminary results are presented here.

SIMULATIONS

The SPI instrument is a coded-mask telescope based on 19 Ge detectors, described in detail in Vedrenne et al. (1999). Simulations have been made using software from the SPI Observation Simulator, consisting of a skymap generator, instrument response convolution and Poisson data generator, and maximum entropy imaging deconvolution (Strong et al., 1999). The instrument response is obtained by GEANT simulations (see Sturner et al. this conference, poster 7.56). Background is added according to computations by P. Jean (Jean et al., 1996). Gamma rays may interact with just one detector ('singles') or scatter to hit other detectors ('doubles', 'multiples'). Singles and doubles are used in this analysis: double hits improve the efficiency especially at higher energies where many events are multiple, and this also improves the signal/background ratio. An exposure of 10^6 seconds corresponding to the INTEGRAL Core Program Category III source time was adopted for illustration. The pointings follow a grid pattern over 10^o X 10^o with 2^o spacing. This 'dithering' is used to determine the detector background values in the imaging analysis; all 19 detector backgrounds are fitted simultaneously with the image pixels. (The case of an independently determined background may be simulated for comparison, but this is not presented here). Another approach to imaging, using matrix methods, is presented at this conference by Connell and Skinner, paper 7.02.

BROAD LINES FROM SNR

A critical issue for the imaging of SNR is the line width: while the SPI Ge detectors have a resolution of about 2.6 keV at 1 MeV, this can only be fully exploited for sources with intrinsically narrow lines. For broader lines the signal-to-noise decreases roughly as the square-root of the line-width, due to background continuum under the line. SNR like Cas A however have shell expansion velocities of a few 1000 km s^{-1} (Fesen et al., 1988) and up to 13000 km s^{-1} in the Cas A jet (Fesen & Gunderson, 1996). High velocities are also seen in IR lines of Ar, S etc.

observed by ISO (Arendt et al., 1999). If we adopt such velocities as the upper range for the inner supernova ejecta they correspond to a line-width for the 1157 keV ^{44}Ti line of roughly

$$\Delta E = 2[v/c]E = 7.7\ [v/1000\ \mathrm{km\ s^{-1}}]\ \mathrm{keV}$$

We note however that ^{44}Ti in core collapse supernovae would originate from very inner regimes, very close to the 'mass cut', the coordinate separating ejected material from material that ends up on the compact supernova remnant (NS/BH). Therefore the ejection of any ^{44}Ti in such a supernova is subject to details which may raise or lower the mass cut coordinate, and hence the amount of ^{44}Ti ejected in the supernova can vary by large factors. However the bulk of ^{44}Ti will be 'barely' ejected, hence at low velocities. Nevertheless convection and Rayleigh-Taylor instabilities in the inner supernova may result in significant mixing of inner material as well, and hence a tail of ^{44}Ti at larger radii may develop, with velocities as high as those of other envelope material for this fraction of the ejected ^{44}Ti (Diehl & Timmes, 1998). The evidence from Chandra for Fe-rich ejecta in knots at the outermost edge of Cas A (Hughes et al., 2000; Hwang et al., 2000), and from ISOCAM NeII and silicate dust images (Douvion et al., 1999) indicate the effects of such mixing.

CAS A

We concentrate on the ^{44}Ti 1157 keV line here; the other lines at 68 and 78 keV will be considered elsewhere (see also Georgii et al., these proceedings). For the simulations of Cas A we assumed a ^{44}Ti 1157 keV flux of 2 10^{-5} cm^{-2} s^{-1}, and no underlying diffuse emission nor continuum. The cases of a narrow line (instrument resolution 2.6 keV) and line widths 10, 20 and 40 keV corresponding to 0,1300, 2600 and 5200 km s^{-1} were simulated. The images illustrate the fact that while the source is detected very significantly for narrow and moderately broadened lines, it gradually descends below the detectability limit for high expansion velocities. For this reason longer exposure times are to be preferred; however since the actual line width is unknown (and determination of the line shape, width and centroid is one of the goals of SPI) the required exposure can only be determined after the first observations are made. In addition there is a requirement for obtaining the background by another method than the dithering - for example by interpolating energy bands adjacent to the line, or 'OFF' observations with the object of interest outside the instrument field-of-view.

In the case that the line is indeed significantly Doppler broadened, the measurement of the line profile by SPI will provide useful information on the mixing of ejecta described in the previous section; however as we have shown long exposure times (e.g. 10^7 s) will be required for this.

VELA REGION

The exposure envisaged for the Vela region as part of the Core Program will be 10^6 sec. Several objects are candidate sources of radioactivity γ-ray lines: the WR star γ^2-Velorum seems less bright in ^{26}Al than expected (Oberlack et al., 2000) ; the Vela SNR at distance 250 pc could not be resolved by COMPTEL above the other emission (Diehl et al., 1999) and may be hard to detect for SPI as well due to its low surface brightness; the newly discovered X-ray SNR RX J0852.0-4622 is possibly the most promising source because it may be a young, closeby object in which case both ^{44}Ti and ^{26}Al may be expected (Aschenbach et al., 1999) although there is now evidence for a larger distance (Slane et al., 2001). For ^{26}Al emission, superimposed sources distributed along the Vela molecular ridge provide an intense background, probably dominating above the individual objects (Diehl et al., 1999) .

Here we consider only the case of one SNR; simulation of all the potential sources in the regions is the subject of ongoing work. We choose the case of the newly-discovered SNR RXJ 0852-4622 as our example. For ^{44}Ti the situation for detectability of the new SNR is probably similar to that for Cas A, and depends strongly on the source flux and the line-width. The ^{26}Al flux would be 2 10^{-5} cm^{-2} s^{-1} for a yield of 10^{-4} $M_\odot$ at an adopted distance of 230 pc. This has been used as the basis for the simulation shown here. The line width for SNR RX J0852 for an age of $\sim$700 years would fall somewhat below that of the Cas A case, and we adopt the lower range of typical velocities here. Because of the larger mask transparency and higher background the ^{26}Al sensitivity is worse than for ^{44}Ti so that at this flux level a detection is only expected for a narrow or slighly broadened line (5 keV: 650 km s^{-1}). Extended ^{26}Al emission from the Vela region with a spatial extent of 10^o will require longer exposures than those considered here for effective detection (note that COMPTEL had several months of exposure in this region).

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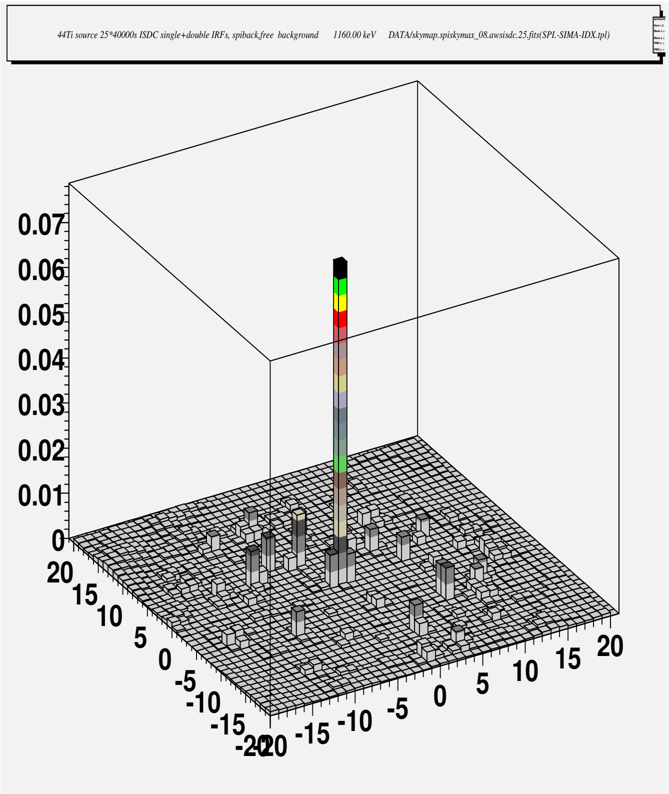

Figure 1. Cas A ^{44}Ti 1157 keV line, narrow line, 10^6s exposure simulation

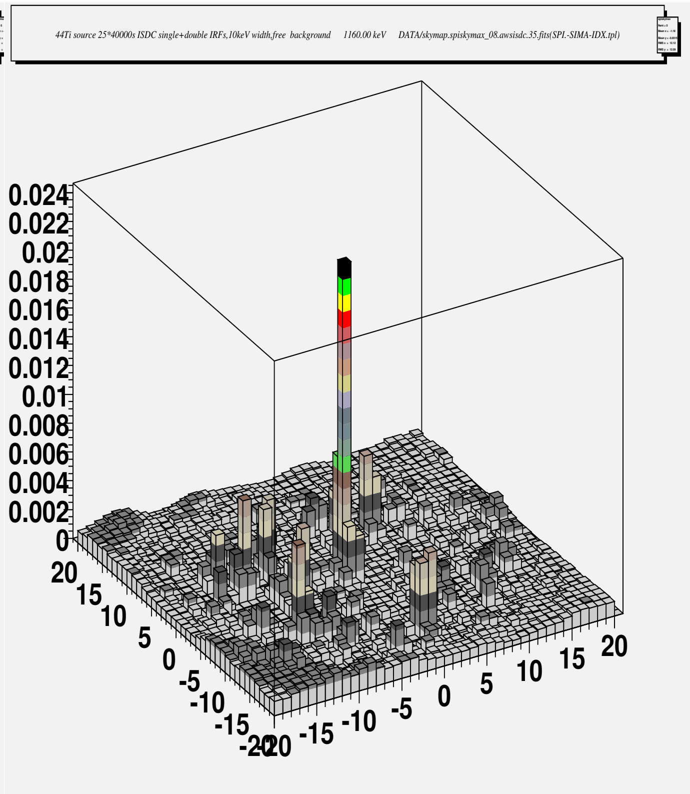

Figure 2. Cas A ^{44}Ti 1157 keV line, 10 keV line-width (1300 km s^{-1}), 10^6s exposure simulation

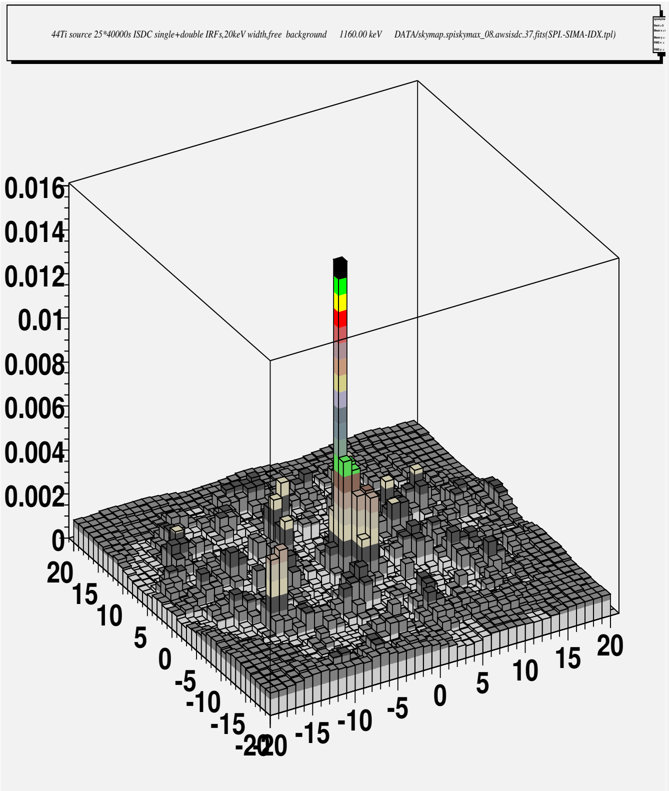

Figure 3. Cas A ^{44}Ti 1157 keV line, 20 keV line-width (2600 km s^{-1}), 10^6s exposure simulation

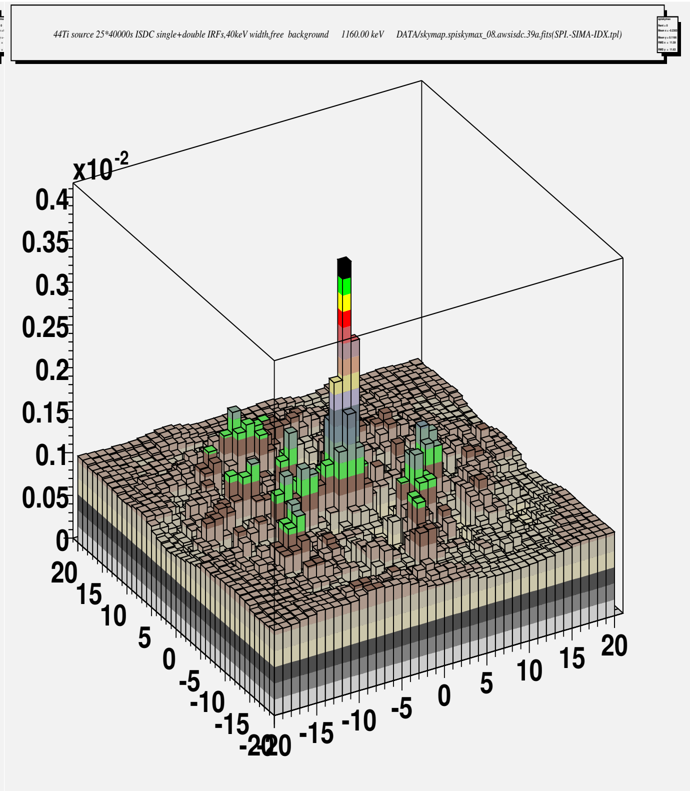

Figure 4. Cas A ^{44}Ti 1157 keV line, 40 keV line-width (5200 km s^{-1}), 10^6s exposure simulation

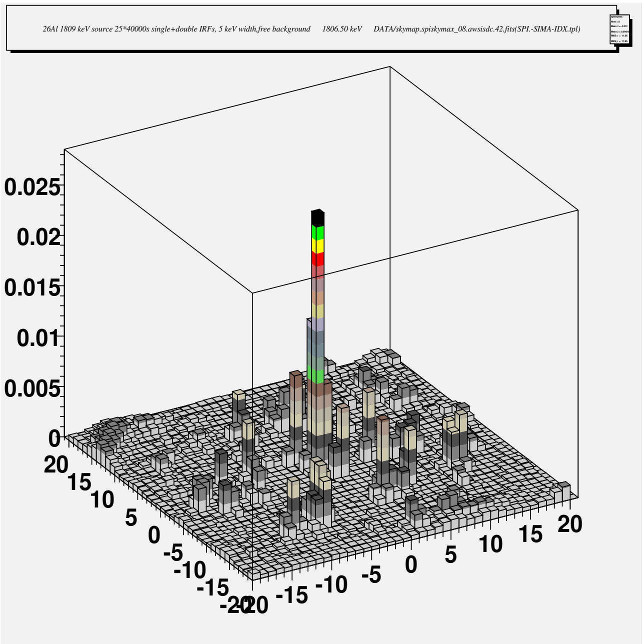

Figure 5. SNR RX J0852.0-4622, ^{26}Al 1809 keV line, 5 keV line width (650 km s^{-1}), 10^6s exposure simulation

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