PROSPECTS OF THE OBSERVATIONS WITH SPI IN THE LIGHT OF THE ^{44}TI γ-RAYS

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ABSTRACT

The recent detection of a supernova remnant in the light of the 1157 keV γ-ray decay line of ^{44}Ti with COMPTEL underlines the importance of this method in detecting young supernova remnants. The prospects for the observation of near-by supernova remnants in the γ-rays from the ^{44}Ti decay will be presented using the latest information about the spectral resolution and the expected background of the spectrometer SPI on-board INTEGRAL. Observation times for various candidate objects are estimated, taking into account the uncertainties in distances, expansion velocities, source strengths and instrumental parameters. We compare different estimations based on the published sensitivity of the instrument SPI.

Key words: SPI; sensitivity;^{44}Ti, supernova remnant.

1. THE FORMALISM

1.1. Estimation of the source flux

The number N_{Ti} of radioactive ^{44}Ti nuclei, being produced in an supernova event can be derived using

$$N_{Ti} = \frac{M_{Sun} \cdot y_{Ti}}{m_{Ti}} \cdot \exp\left(\frac{-t_{SN}}{\tau_{Ti}}\right) \quad , \qquad (1)$$

with m_{Ti} the mass and $\tau_{Ti} = 90$ yr (Aschenbach et al. (1999)) the life time of ^{44}Ti. y_{Ti} is the mass yield of ^{44}Ti in this supernova event given in fractions of the solar mass M_{Sun}. The time since the supernova exploded is denoted with t_{SN}.

From the distance D to the supernova remnant the flux Φ_{Ti} for the isotope ^{44}Ti can then be found using

$$\Phi_{Ti} = \frac{N_{Ti}}{\tau_{Ti} \cdot 4\pi \cdot D^2} \quad . \qquad (2)$$

1.2. Estimation of the observation time with SPI

For the Ge-detector array of SPI the flux Φ of a source (with the significance n) is given

$$\Phi = \frac{n \cdot \sqrt{R \cdot T_{eff} + b \cdot \Delta E \cdot T_{eff}}}{X} \quad . \qquad (3)$$

b, in units of [(MeV s)$^{-1}$] is the background in the detector array and has been determined via Monte Carlo simulations by Jean (1996) for SPI. ΔE is the energy interval under consideration. $R = \Phi \cdot A_{eff}$ is the number of source counts per second, but is usually so small that it can be neglected for small significanes of the source. The exposure $X = A_{eff} \cdot T_{eff}$, where T_{eff} is the effective observation time, i.e. the "pure"observation time without taking into account losses from the dead time, belt passages etc. The effective area A_{eff} can be written as

$$A_{eff} = A \cdot \epsilon \cdot t \cdot \frac{10}{19} \quad . \qquad (4)$$

ϵ is the efficiency of the Ge-detector array, t denotes the transmission of the material in the field-of-view (FoV) and A is the geometric area of the Ge-detector array of 500 cm^2. Since for a source at infinity the mask always obscures 9 out of 19 detectors, the effective area has to be corrected for.

Now the minimal effective observation time for SPI is found to be

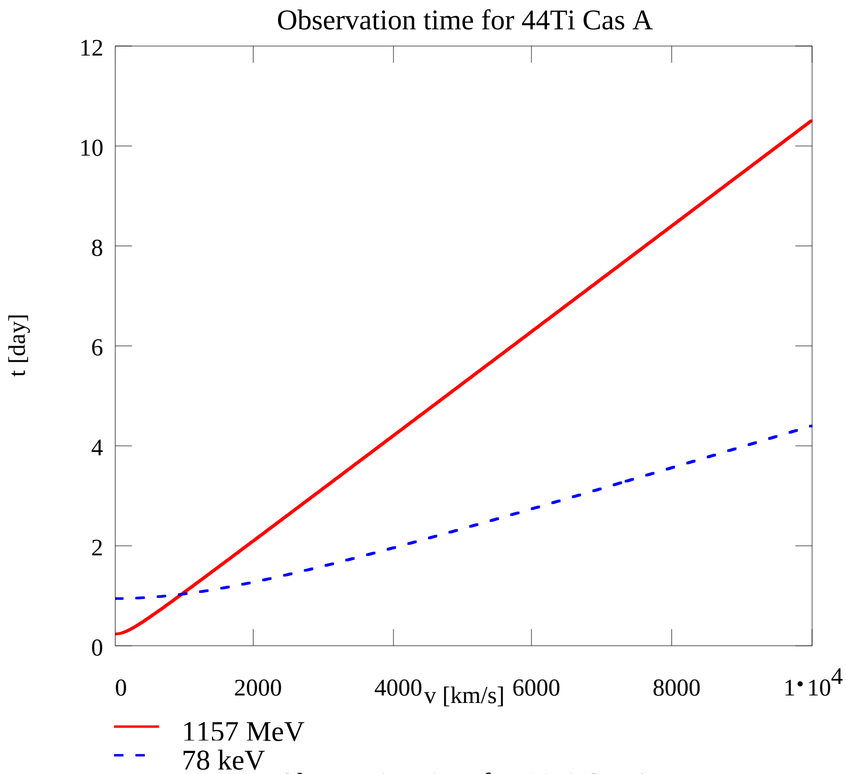
$$T_{eff} = \frac{n^2 \cdot b \cdot \sqrt{(\frac{2 \cdot v \cdot E}{c})^2 + (\Delta E_{Ge})^2}}{(A_{eff} \cdot \Phi)^2} \quad , \qquad (5)$$

where the astrophysical Doppler broadening due to velocity v of the ejected material in the supernova explosion is taken into account. ΔE_{Ge} is the instrumental energy resolution of the Ge-detectors of SPI.

2. RESULTS

2.1. For specific sources

Using the measured energy resolution of a prototype detector from SPI and the other instrumental parameters from Monte Carlo simulations, we can derive



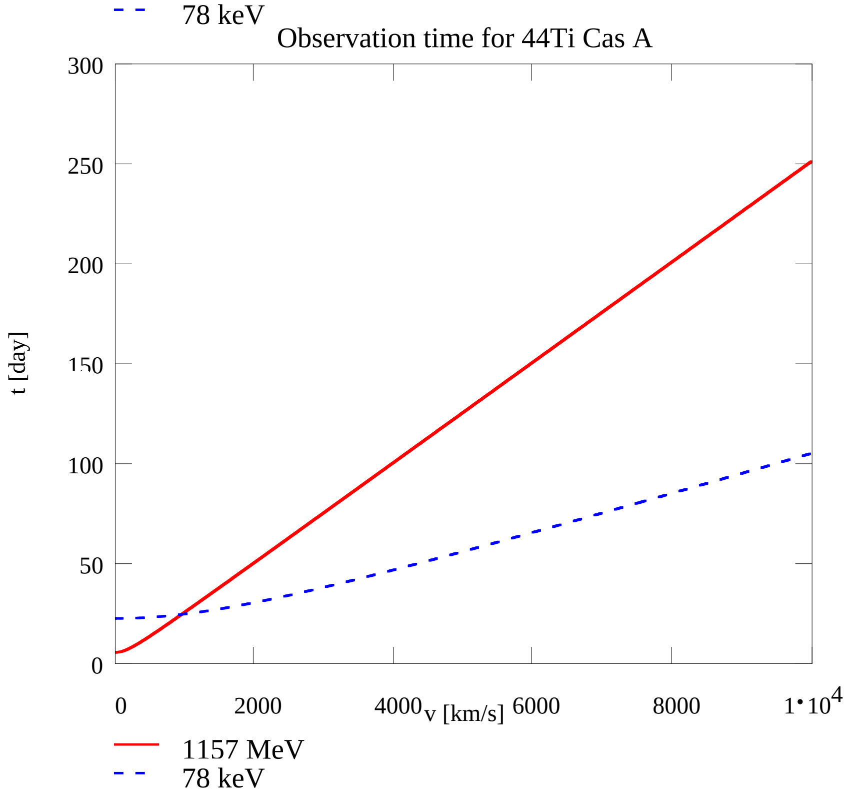


Figure 1. The effective observation time versus the velocity of the ejecta for Cas A in an optimistic (top) and a pessimistic (bottom) case. For both cases the solid line denotes the 1157 keV line and the dotted line represents the 78 keV line of ^{44}Ti.

Table 1. Parameters used for the examples.

	Cas A (upper limit)	Cas A (lower limit)	RX J0852.0-4622	SN 1987A
Distance [kpc]	2.8	3.4	200	44500
Age [yr]	320	342	700	15
mass yield y_{Ti}	$1.3 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$
Flux [Phot./(cm^2 s)]	$3.8 \cdot 10^{-5}$	$7.8 \cdot 10^{-6}$	$4.3 \cdot 10^{-5}$	$2.7 \cdot 10^{-6}$

the effective observation time for a 3σ-detection in the 1157 keV and the 78 keV lines of ^{44}Ti for the following supernova remnants:

2.1.1. Vela junior: RX J0852.0-4622

From the parameters of the third row of Table 1 a flux of $4.3 \cdot 10^{-5}$ photons/(cm^2 s) can be expected. The effective observation time for this case is shown in Figure 2.

2.1.2. Supernova SN 1987A

For an observation of SN 1987A in the first year of the INTEGRAL mission (2002) and the parameters of the fourth row of Table 1 the expected effective observation time is shown in Figure 3.

2.1.3. Cas A

For this source two different scenarios are considered. The optimistic case, with the parameters shown in the first row of Table 1 yields a ^{44}Ti flux of $3.8 \cdot 10^{-5}$ photons/(cm^2 s), whereas the pessimistic case with the parameters from the second row of Table 1 gives $7.8 \cdot 10^{-6}$ photons/(cm^2 s). For both cases the effective observation time versus the velocity of the ^{44}Ti supernova ejecta obtained from equation (5) is shown in Figure 1.

2.2. In general

For a typical observation period of 10^6s (12 days) we can plot the viewing distance in the light of radioactive ^{44}Ti versus the expansion velocity of a SN remnant by solving equation (5) for the distance:

$$D = \frac{1}{2\sqrt{\pi}} \cdot \left(\frac{A_{eff}^2 \cdot N_{Ti}^2 \cdot T_{eff}}{n^2 \cdot \tau_{Ti}^2 \cdot b \cdot Y} \right)^{1/4} , \qquad (6)$$

where $Y = \sqrt{(2vE/c)^2 + (\Delta E_{Ge})^2}$.

Taking the parameters of the two examples for Cas A, the viewing distance can be plotted in dependence on the background of SPI as shown in Figure 4. The background is from Monte Carlo simulations, including low-energetic neutron capture reactions with

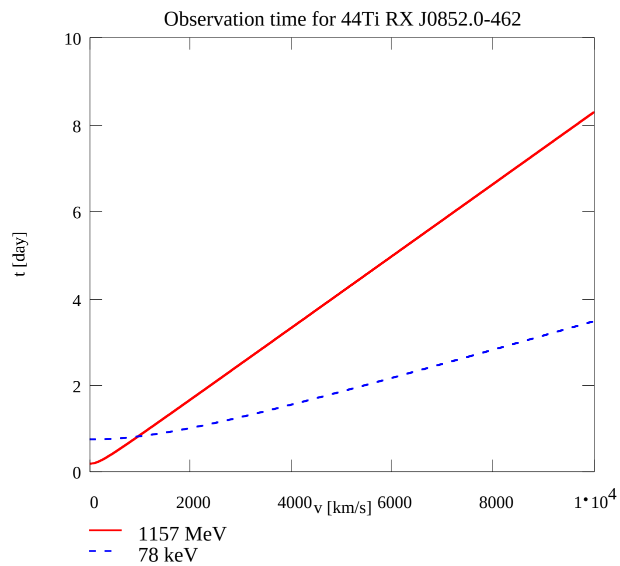


Figure 2. The effective observation time versus the velocity of the ejecta for RX J0852.0-4622. The solid line denotes the 1157 keV line and the dotted line represents the 78 keV line of ^{44}Ti.

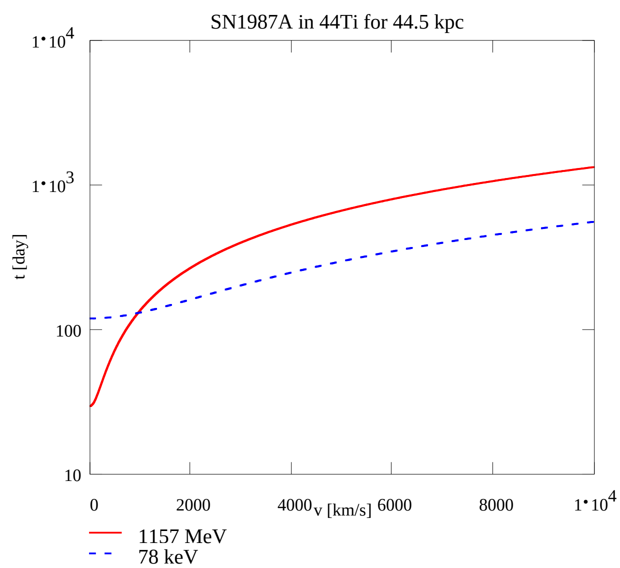


Figure 3. The effective observation time versus the velocity of the ejecta for SN 1987A. The solid line denotes the 1157 keV line and the dotted line represents the 78 keV line of ^{44}Ti.

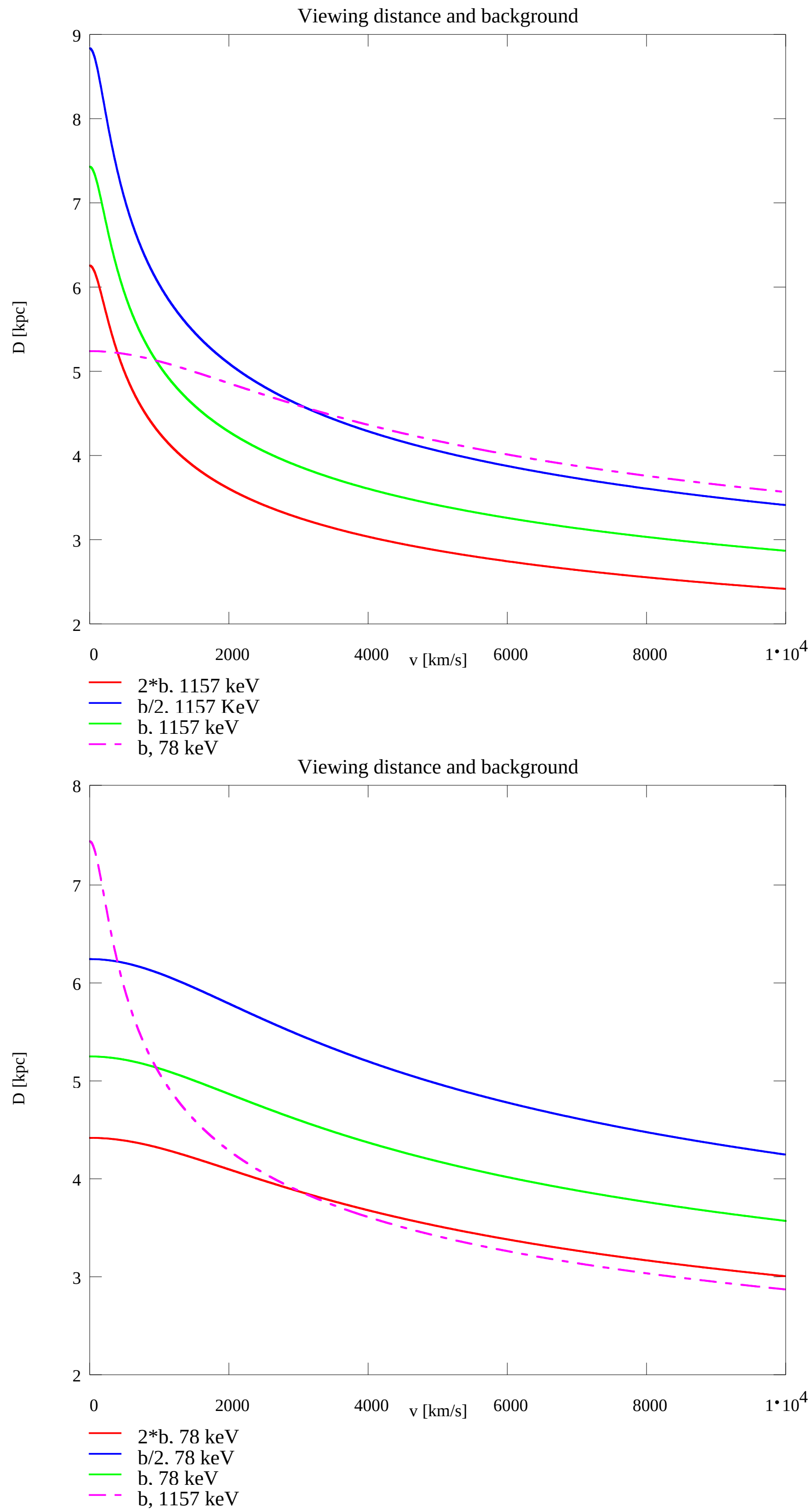


Figure 4. The viewing distance in the 1157 keV line (top) and the 78 keV line (bottom) of radioactive ^{44}Ti *versus energy. 3 different background values, nominal, twice the nominal and half the nominal (shown by the middle, top and lower curve) were assumed for the instrumental background.*

widely unknown cross-sections, and can be wrong by a factor of 2. Therefore three curves are shown in Figure 4. They represent the viewing distance for the nominal background and for twice and half of this background, respectively (middle, top, bottom curve).

3. CONCLUSIONS

From all these examples it becomes evident, that for expansion velocities above 1000 km/s the observation in the 78 keV line is much more effective than using the 1157 keV line. This is due to the smaller effect of Doppler broadening for the 78 keV line, which compensates the lower sensitivity of SPI in the X-ray domain.

Furthermore it is important to note that considerable effective observation times are needed for detecting SN-remnants. Only if the expansion velocities are small, a deep view into our galaxy seems possible (see the 1157 keV line in Figure 4).

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