Galactic distribution of 1.275 MeV emission from ONe novae

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ABSTRACT Modelisations of galactic 1.275 MeV emission produced by the decay $^{22}\text{Na}$ have been performed for several frequency-spatial distributions of ONe novae. Recent results of nova rates and their distributions in our Galaxy have been used. These modelisations allow to estimate the lower-limit of the $^{22}\text{Na}$ mass ejected per ONe nova detectable with the future spectrometer (SPI) of the INTEGRAL observatory as a function of their frequency-spatial distribution in the Galaxy. Calculations using recent estimations of the expected $^{22}\text{Na}$ mass ejected per ONe nova show that the diffuse galactic 1.275 MeV emission will be difficult to detect with SPI.

KEYWORDS: gamma-rays: general - Galaxy: structure - stars: classical novae

1. INTRODUCTION

Observations with several instruments have reported upper-limits on the 1.275 MeV flux from the Galaxy (HEAO-3, SMM) or from individual novae (COMPTEL). Leising et al. (1998) found a 99% confidence limit of $1.2 \times 10^{-4}$ photons cm$^{-2}$ s$^{-1}$ on a steady 1.275 MeV flux from the Galactic center direction. Iyudin et al. (1995), using COMPTEL observations of single novae, estimate a $2\sigma$ upper-limit of $3 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ for any neon-type novae in the galactic disk, which has been translated into an upper-limit of the ejected $^{22}\text{Na}$ mass of $3.7 \times 10^{-8}$ $M_\odot$. The next generation of $\gamma$-ray spectrometers should have the sensitivity required for the detection of the 1.275 MeV emission from classical ONe novae. SPI, the future spectrometer of the INTEGRAL observatory will be operational in the beginning of 2001. With its high-resolution, the spectrometer is designed for the detection of astrophysical $\gamma$-ray lines. SPI will be also able to perform images with an angular resolution of $\approx 3^\circ$ by using a coded aperture system. For a more detailed description of the spectrometer see Vedrenne et al. (1998). Using sensitivity estimation and calculations of $^{22}\text{Na}$ yields in ONe novae, Hernanz et al. (1998) estimate that the 1.275 MeV line from a nova could be detected by SPI if its distance is less than $\approx 0.5$ kpc. In the presented work, we check the possibility to detect with SPI the cumulative emission from the $^{22}\text{Na}$ ejected by ONe novae. The total Galactic flux at 1.275 MeV depends on the amount of $^{22}\text{Na}$ ejected per outburst and the Galactic ONe nova rate. However, the latter is poorly known because the interstellar extinction prevents us from directly observing in the visible more than a small fraction of novae per year. Since 1954, several methods have been used to estimate occurence
rate of novae giving different results. Recently, Shafter (1997) reconciled these differences by recomputing the nova rate with the galactic nova data. He extrapolated the global rate with the observed one accounting for surface brightnesses of the Galaxy and correction factors to take care of any observational incompleteness. He estimated the nova rate to be $35 \pm 11 \text{ yr}^{-1}$. Hatano et al. (1997) found a similar value ($41 \pm 20 \text{ yr}^{-1}$) using a Monte-Carlo technique with a simple model for the distribution of dust and novae in the Galaxy. Livio & Truran (1994) estimated the frequency of occurrence of ONe novae, in light of observation of abundances in nova ejecta. They estimate a fraction of ONe novae between 11% and 33%. We modelize the Galactic emission at 1.275 MeV as a function of the ONe nova rate and the mean $^{22}\text{Na}$ yield per outburst. This has been done for several spatial distributions of novae in the Galaxy. The observation time necessary for a detection with SPI of $^{22}\text{Na}$ emission is estimated as a function of the mean mass of $^{22}\text{Na}$ ejected per nova.

2. METHOD

The method consists of: (1) a simulation of a set of ONe novae that is representative of what could be the galactic nova distribution at a given time. (2) An analysis of the distribution of the 1.275 MeV emission and a check of whether SPI will be able to detect it. And, at least, (3) an estimation of the frequency of detection by analysing a large number of Galaxy-tests.

2.1 Modelisation of galactic 1.275 MeV emission

The galactic distribution of the 1.275 MeV emission from ONe novae is calculated with a Monte-Carlo simulation. The position in Galactocentric coordinates and the age of ONe novae are chosen randomly according to the appropriate distributions. The number of simulated ONe novae depends on their frequency and the total period during which ejected $^{22}\text{Na}$ is an effective emitter. As proposed by Higdon & Fowler (1987, hereafter HF87), it has been assumed that the emissivity of novae older than 5 times the $^{22}\text{Na}$ mean life contributes negligibly to the diffuse 1.275 MeV emission. The $^{22}\text{Na}$ mass ejected per nova and the rate of novae are parameters of the modelisation. We have selected four models of distribution of novae in the Galaxy that differ significantly each other. The first of them is described in HF87. They assumed that the novae are distributed like stars. The second model has been used by Hatano et al. (1997) to estimate the spatial distribution and the rate of Galactic novae. It is based on a model of the distribution of SNIa by Dawson & Johnson (1994, hereafter DJ94). Since SNIa are probably the result of the thermonuclear explosion of a mass-accreting white dwarf, their distribution should be close to the novae one. The third model is derived from the galactic survey of the Spacelab InfraRed Telescope that provides a reliable tracer of the distribution of G and K giant stars (i.e. old population stars - see Kent, Dame & Fazio, 1991, hereafter KDF91). The last model is taken from Van der Kruit (1990, hereafter VdK90). It has been used by Shafter (1997) to estimate the nova rate in our Galaxy. He assumed that the nova distribution follows the brightness profile of our Galaxy.
According to recent results (see section 1), we did calculations for ONe nova rate ranging from $2 \, \text{yr}^{-1}$ to $18 \, \text{yr}^{-1}$.

2.2 Observation of the galactic 1.275 MeV emission by SPI

Jean et al. (1997) have estimated the narrow line sensitivity of SPI for an on-axis point source by computing instrumental background with detailed physics Monte-Carlo simulations. However, the 1.275 MeV line is 20 keV width (see Hernanz et al., 1998) and this sensitivity become $2.2 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ (3σ, 10$^6$ s observation time). Moreover, the emission is diffuse and the spectrometer will provide (1) a distribution of intensity in pixels and (2) a total flux in the field-of-view. The both cases have been investigated for the analysis of Galaxy-tests. In the case 1, distribution of the intensity has been calculated with $3^\circ$ by $3^\circ$ size pixels (SPI angular resolution). A rough estimation of the significance, for a detection of at least one excess in the distribution of the intensity, is derived by computing the probability that the observed distribution is due to background fluctuations. The analysis in the case 2 is similar to an on/off pointing method analysis. The sensitivity of such a mode of detection is $3.1 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$.

2.3 Probability to detect the 1.275 MeV line with SPI

Several Monte-Carlo simulations have been done for a given galactic ONe-novae frequency-spatial distribution and a value of the $^{22}$Na yield per nova. For a large number of Galaxy-tests, the probability for a detection of the cumulative emission has been estimated by calculating the fraction of time the observation of the simulated flux give a significance larger than 3σ. The average observation time needed to have 90% of chance for a detection of this emission has been derived.

3. RESULTS

Figure 1 shows the observation time needed to have 90% of chance that SPI detect the 1.275 MeV line (case 2) from the GC region as a function of the mean $^{22}$Na mass ejected per ONe nova. These results are displayed for the 4 spatial distributions. The time needed for a detection of the cumulative emission for models KDF91 and HF87 are lower than those of VdK90 and DJ94. The Galactocentric scale radius of the exponential disk for the former models are 3 kpc and 3.5 kpc respectively whereas it is higher (5 kpc) for the model VdK90 and DJ94. Since the novae are closer to the GC in the KDF91 and HF87 models, the 1.275 MeV flux is larger and more compact. The mean simulated 1.275 MeV flux from the $12.5^\circ$ around the GC, normalized to the $^{22}$Na yield per outburst and the rate of ONe novae (in photons cm$^{-2}$ s$^{-1}$ M$\odot^{-1}$ yr), are $78.0\pm2.4$, $56.8\pm3.5$, $105.1\pm2.9$ and $56.4\pm1.4$ for the HF87, VdK90, KDF91 and DJ94 model respectively. SPI will need 10 times more observation time for a detection of an excess in the pixel distribution.

4. CONCLUSION

According to Hernanz et al. (1998), the $^{22}$Na average yield could be between $3 \times 10^{-9}$
Figure 1: SPI observation time needed for a detection of the 1.275 MeV emission of the GC region as a function of the $^{22}\text{Na}$ yield per nova and for 4 galactic distributions.

and $1.2 \times 10^{-8} \text{ M}_\odot$ per nova. There is few chance to detect the galactic diffuse 1.275 MeV emission with SPI with $\approx 10$ days of observations. However, a 80 days of observation of the GC region could already give constraints for the mean $^{22}\text{Na}$ yield per ONe novae and for their distribution in the Galaxy. Therefore, $\gamma$-ray observation of novae would provide information not only on their eruption mechanisms and the nucleosynthesis processes involved in their explosion but also on their distribution in the Galaxy.

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