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COMPTEL Constraints on Nova-Produced ^{22}Na

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ABSTRACT After 6 years of the Compton Mission (CGRO) the COMPTEL telescope has achieved an MeV γ-ray line sensitivity of about 10^{-5} photons/(cm^{2}s). At this level of sensitivity quite high expectations can be placed on the detection of the predicted ^{22}Na γ-ray line from nearby novae. Classical novae provide an environment in which hydrogen-burning reactions proceed on CNO and heavier nuclei at high temperatures. For such conditions astrophysically significant fluxes of the ^{22}Na γ-ray line at 1.275 MeV are expected. The present understanding is that the nova shell expelled by the thermonuclear runaway should be transparent to 1.275 MeV line emission a few days after the nova explosion.

We have used the COMPTEL database to improve previously published limits for the sodium production by neon novae in the Galaxy, and to constrain the recent theoretical predictions of nova yields.

KEYWORDS: all-sky survey; γ-ray line emission; galactic novae; abundances.

1. INTRODUCTION

The classical nova outburst has been modelled as a thermonuclear runaway in the accreted hydrogen-rich envelope of the white dwarf companion of a close binary system (e.g. Starrfield et al. 1974; Truran 1982). In general, observations of novae support such models (Gallagher & Starrfield 1978; Gehrz et al. 1998).

It is currently believed that neon novae, a distinct subclass of the classical novae, associated with an underlying oxygen-neon-magnesium (ONeMg) white dwarf, may be an important source of Galactic ^{22}Na (Clayton & Hoyle 1974). ^{22}Na decays with the 3.75 yrs life-time to a short lived excited state of ^{22}Ne at 1.275 MeV. The accumulation of ^{22}Na from the frequent novae in the central bulge of the Galaxy may lead to an observable diffuse emission from that region. In addition, an individual nova at 1 kpc from the Sun with a total ejected mass of the order of 10^{-4} $M_\odot$ and a ^{22}Na mass fraction of the order of 10^{-4} should produce a flux value of 4×10^{-5} cm^{-2} s^{-1} (Weiss & Truran 1990).

The COMPTEL telescope with its large field of view was used to search for ^{22}Na emission from a number of recent Galactic novae. No positive detection was reported for any of the five neon-type novae (NHer 1991, NSgr 1991, NSct 1991, NPup 1991 and NCyg 1992), and an average 2 σ upper limit on the ejected ^{22}Na mass for any neon-type novae in the Galactic disk of 3.7×10^{-8} $M_\odot$ was derived (Iyudin et al. 1995). This upper limit is much lower than those previously derived by HEAO-3 (Mahoney et al. 1982), SMM (Leising et al. 1988) or OSSE (Leising et al. 1993).

Since that time COMPTEL accumulated more data in the course of the CGRO mission, and these were used for the production of a first all-sky map in the 1.275 MeV ^{22}Na emission. Preliminary results are presented below.

2. INSTRUMENT, DATA ANALYSIS AND RESULTS.

COMPTEL, due to its combination of imaging and spectroscopic capabilities (Schönfelder et al. 1993), provides a unique opportunity to measure line emission from extended regions (e.g. the Galactic bulge) or from point-like sources.

For the all-sky map we have combined data of all viewing periods up to the end of CGRO Cycle 5 (VP531) in a $\pm 2\ \sigma$ energy window around the 1.275 MeV line, where σ is the instrumental energy resolution for this line. The background model used in this work is based on the empirical modelling of event distributions in the (χ, ψ) data space, which is energy independent in first aproximation (Knödlseder et al. 1996), and event distributions in the $\bar{\varphi}$ coordinate of the line photons. Some smoothing is then applied in the χ and ψ coordinates to reduce statistical fluctuations. Effects of increasing ^{22}Na activation, and decay inside COMPTEL, will generally lead to an increase in the background in the ^{22}Na energy interval. The influence of the ^{22}Na activation on the data analysis is still under investigation, hence the presented results should be regarded as preliminary.

For the single nova analysis we have used data from the viewing periods covering the position of the relevant nova. In calculating the ^{22}Na mass in the ejected shell, the time delays between nova maximum brightness and the time of COMPTEL's measurements have been taken into account. The derivation of ^{22}Na mass limits from the 1.275 MeV line flux measurements for a single nova is hampered by the fact that in many cases the nova progenitor was not observed prior to the nova outburst. Even relatively well studied novae are subject to uncertainties in the distance estimate and in the derived abundances. Few examples of such uncertainties are presented in recent publications (Arkhipova, Esipov and Sokol 1997; Gertz et al. 1998).

Generally, different viewing periods were combined to achieve the best possible sensitivity for the novae. The optimal COMPTEL pointings sequence should ideally be arranged as a series of at least three observations with the pointings 6°-10° off the position of the nova, arranged symmetrically around the nova position. The duration of each observation should be at least 2 weeks, with an interval of about one month between observations. Unfortunately, only observations with large off-angles ($\sim 40^o$ off the position of the particular nova) were available for the recent classical novae like NCas 1993, NCas 1995, NCen 1995, NCir 1995 and NCru 1996. For such observations the sensitivity of the instrument is noticeably worse than for the optimal pointings sequence and, additionally, such sets of observations are very difficult for the spectral analysis of the novae line emission.

These considerations and an uneven exposure of the galactic plane by COMPTEL (see paper on ^{44}Ti all-sky imaging by Iyudin et al., these proceedings), have forced us to restrict our analysis to the case of NCyg 1992 and to the general cases of disk and bulge novae populations. Table 1 summarises the COMPTEL 2 σ upper-limits on the ejected mass from the NCyg 1992 nova and two galactic novae populations, where disk novae population was defined as in Iyudin et al. (1995), and bulge novae were defined as novae contained in a circle of 10^o radius (galactic coordinate system) around the galactic center. A canonical frequency of 40 yr^{-1} was used in the estimate of the average ^{22}Na mass ejected per bulge nova. The revised upper limit of the ^{22}Na yield from Nova Cyg 1992 is based on the improved flux upper limit of COMPTEL (total observing time of 3.6×10^6 s) and a better measured distance to this nova (Chocol et al. 1997).

Table 1. COMPTEL 2 σ upper limits to ^{22}Na fluxes and yields from recent Galactic novae.

Nova name	Date, TJD	Nova Type	d, kpc	1.275 MeV flux (10^{-5} photons·cm^{-2}s^{-1})	^{22}Na yield, ($10^{-9}M_\odot$)
Nova Cygni 1992	8672	ONe	1.77	$\leq$2.1	$\leq$21
disk nova	—	ONe	2.0	$\leq$3.3	$\leq$37
bulge nova	—	ONe	8.5	$\leq$3.0	$\leq$3.6

Latest predictions of the ^{22}Na mass ejected as the result of thermonuclear runaway on the white dwarf in a binary system are as small as $\leq2.0\times10^{-9}$ $M_\odot$ (Gomez-Gomar, Hernanz, Jose and Isern 1998; Jose and Hernanz 1998; Starrfield et al. 1998). But these results were derived using reaction flows in which notable uncertainties in cross-sections of several key reactions still exist (Coc et al. 1995). It is important to note, that high masses of the ejected nova shell are not reproducible by the models. This may force one to broaden possible scenarios of the prenova evolution and of the runaway process (Glasner, Livne and Truran 1997; Kovetz and Prialnik 1997; Starrfield et al. 1998).

The excess in the all-sky 1.275 MeV line emission map with the highest likelihood ratio was detected from the south Aquila region (l=29^o, b=-11^o). This excess has a likelihood ratio of $\sim$ 26, that corresponds to a 4.3 σ detection for 3 d.o.f.. With all trials being taken into account the detection significance decreases to $\sim$2.7 σ. Given our systematic uncertainty in the background modelling, we do not regard this as a significant excess at this point.

3. CONCLUSIONS

^{22}Na gamma-ray line emission at 1.275 MeV from novae in our Galaxy still remains to be detected. For a direct comparison of runaway models with high-mass white dwarfs in binary systems, one has to succeed in measuring of a light curve of nearby (less than 1 kpc from the Sun) neon-type novae. This will hopefully be achieved with the next generation of space-borne γ-ray line spectrometers like the spectrometer SPI with a better sensitivity to MeV lines.

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