GAMMA-RAY EMISSION OF CLASSICAL NOVAE
AND ITS DETECTABILITY BY INTEGRAL

M. Hernanz 1, J. Gómez-Gomar 1, J. José 1,2, A. Coc 3, J. Isern 1

1) Institut d’Estudis Espacials de Catalunya IEEC/CSIC/UPC, Edifici Nexus, C/Gran Capità 2-4, 08034 Barcelona, SPAIN, 2) Departament de Física i Enginyeria Nuclear, UPC, Avda. Víctor Balaguer s/n, 08800 Vilanova i la Geltrú, Barcelona, Spain, 3) Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM, IN2P3-CNRS, Bât. 104, 91405 Orsay, France

ABSTRACT A lot of information concerning the mechanism of nova explosions will be extracted from the possible future observations with INTEGRAL. In order to be prepared for this task, we are performing a detailed modelization of the γ-ray emission of classical novae, for a wide range of possible initial conditions. New models of classical novae have been computed with a continuously updated hydrodynamical code, including a complete network of nuclear reactions. Spectra at different epochs after the explosion and light curves for the different lines (511, 478 and 1275 keV) and the continuum are presented, as well as detectability distances with INTEGRAL’s spectrometer SPI.

KEYWORDS: gamma-rays; novae; nucleosynthesis; abundances.

1. INTRODUCTION

Accretion of hydrogen-rich matter by a white dwarf, in a close binary system, is at the origin of nova outbursts. The explosion is triggered by the thermonuclear runaway (TNR) that ensues from hydrogen ignition in degenerate conditions at the base of the accreted envelope. During nova explosions, some radioactive nuclei are synthesized which should produce emissions of γ-rays. Both line and continuum emission are expected. The annihilation of the positrons coming from the β+-decay of 13N and 18F (τ=862s and 158 min, respectively) produces emission at 511 keV and below, whereas the decays of 7Be (through an e−-capture) and 22Na (through a β+-decay) emit 478 and 1275 keV photons, with lifetimes of 77 days and 3.75 years, respectively.

A detailed analysis of the γ-ray emission of classical novae requires the coupling of a hydrodynamical code, which gives the detailed nucleosynthesis of the radioactive nuclei, as well as the temporal evolution of the properties of the expanding envelope, to a Monte-Carlo one, able to handle γ-ray production and transfer. The potential importance of γ-ray emission of classical novae had been already pointed out in previous works (Clayton & Hoyle 1974, Clayton, 1982, Leising & Clayton 1987).

2. GAMMA-RAY EMISSION OF INDIVIDUAL CO AND ONe NOVAE
From the observational point of view, two main types of novae can be distin-
guished: standard novae and neon novae. All of them show enhancement in CNO
elements, but neon novae are also particularly enhanced in neon. It is largely ac-
cepted that standard novae are occurring on CO white dwarfs, whereas neon
novae are exploding ONe white dwarfs; in both cases, some initial enrichmen
t of the accreted material through mixing with material from the core (either via diffusion,
dredge-up or other mechanisms) is needed in order to explain the observed abun-
dances and even the explosive process itself. Thus, the initial composition of the
accreted material plays an important role in the outburst properties (José & Her-
nanz 1998). Concerning the $\gamma$-ray emission, we have demonstrated in previous
works that there is a clear distinction between CO and ONe novae. CO novae show
emission at 478 keV, related to $^7$Be–decay, lasting for 2 months, whereas ONe novae
show emission at 1275 keV, related to $^{22}$Na decay, lasting for some years (see Her-
nanz et al., 1996 and Gómez-Gomar et al. 1998 for details). This is a consequence
of the different nucleosynthetic yields of CO and ONe novae (José & Hernanz, 1998,
Kovetz & Prialnik, 1997, Starrfield et al. 1998).

An example of the $\gamma$-ray emission of CO novae is shown in Figure 1, where the
light curves of the 478 keV line for 0.8 and 1.15 M$_\odot$ novae are shown. The width
of the lines (3 and 7 keV) has been taken into account for the determination of the
maximum detectability distance of the line by the future spectrometer SPI onboard
INTEGRAL; this distance is around 0.5 kpc.

Concerning 1275 keV emission, new results since our previous works are shown
in Table 1 and Figure 2. These correspond to a reanalysis of the rates of the
nuclear reactions involved in the synthesis of $^{22}$Na and $^{26}$Al in ONe novae (José,
Coc & Hernanz, 1998), which are the main novae producers of these elements,
mainly because of their initial enrichments in $^{20}$Ne, $^{23}$Na and $^{24,25}$Mg. The new
recommended rates of some key reactions of the NeNa-MgAl cycles and the upper
and lower limits of them, translate into a range of ejected masses of $^{22}$Na, which in
all cases are larger than the old ones (see Table 1). The much lower $^{22}$Na yield of
a CO nova is also shown for comparison. The light curves of the 1275 keV line are
 correspondingly shifted, as is shown in Figure 2 for an ONe nova of 1.25 M$_\odot$. The
new 1275 keV fluxes are larger by, at most, a factor of $\sim$10. Taking into account that
the maximum detectability distances for ONe novae (for INTEGRAL’s spectrometer
SPI) were around 0.5 kpc for the old models (see Gómez-Gomar et al., 1998), we
deduce that in the most optimistic case detectability distances can be as large as 2
kpc, without taking into account the effect of larger ejected masses, which is a long
standing problem of all theoretical models (i.e., the inability to reproduce some
large ejected masses observed; see Starrfield et al. 1998, for a recent discussion
on this topic). The width of the lines is $\sim$20 keV in this case. Up to now, the
COMPTEL instrument onboard the Compton GRO has established upper limits
to the 1275 keV emission from some recent novae, which are compatible with our
computed fluxes (Iyudin et al. 1995). For an analysis of the cumulative 1275 keV
emission from novae in the Galaxy, see Jean et al. 1998 (and these proceedings).

Another important emission of classical novae in the $\gamma$-ray domain is the 511
TABLE 1: \(^{22}\)Na ejected masses (in M\(_{\odot}\)).

| Type | \(M_{WD} (M_{\odot})\) | \(M_{\text{ejec}}(\text{old})\) | \(M_{\text{ejec}}(\text{high})\) | \(M_{\text{ejec}}(\text{low})\) |
|------|-----------------|-----------------|-----------------|-----------------|
| ONe  | 1.15            | 1.0 \(10^{-9}\) | 1.2 \(10^{-8}\) | 3.1 \(10^{-9}\) |
| ONe  | 1.25            | 1.3 \(10^{-9}\) | 9.0 \(10^{-9}\) | 2.9 \(10^{-9}\) |
| ONe  | 1.35            | 2.6 \(10^{-9}\) | 6.2 \(10^{-9}\) | 3.4 \(10^{-9}\) |
| CO   | 1.15            | 3.8 \(10^{-12}\) | –               | –               |

FIGURE 1. Light curves for the 478 kev line \((D=1\text{kpc})\) for CO novae of 0.8M\(_{\odot}\) (dotted line) and 1.15M\(_{\odot}\) (dash-dotted line).

keV line and the continuum below it. This emission, which is produced both in CO and in ONe novae, is by far the most intense one, but it has a very short duration. The reason is that it is related mainly to the disintegration of \(^{13}\)N and \(^{18}\)F, which decay emitting positrons on very short timescales (see above). Thus, only for a very early detection (even before the visual maximum for the majority of the cases) would this emission be detected up to distances of \(\sim\)10 kpc (Hernanz et al. 1996, Gómez-Gomar et al. 1998). In this sense, the use of the shield of the INTEGRAL spectrometer as a nova detector in \(\gamma\)-rays would be of great importance (see Jean et al., these proceedings). However, there are very recent results concerning nuclear reaction rates related to \(^{18}\)F destruction by \((p,\gamma)\) and \((p,\alpha)\) reactions (Utku et al. 1998) which will significantly affect \(^{18}\)F synthesis in novae. Our still preliminary computations indicate that \(^{18}\)F production will be lowered by a factor \(\sim\)10, leading to smaller 511 keV line fluxes and smaller detectability distances (the complete calculation is in progress).

3. CONCLUSIONS

Novae are potential \(\gamma\)-ray emitters, mainly through continuum emission, between \(\sim\)30 and 511 keV, and line emission at 511 keV (all types of novae). This emission
FIGURE 2. Light curves for the 1275 keV line

could be detected with SPI, provided that the novae are caught early enough (even before the maximum in visual light). Line emission at 478 keV (CO novae) and 1275 keV (ONe novae) is less intense than continuum and 511 keV line emission, but has much longer duration, specially the 1275 keV one. Its detection by INTEGRAL would provide an important confirmation of the TNR model of classical novae and insights on the conditions in the expanding ejecta.

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