Thermonuclear Runaways on Accreting White Dwarfs: Models of Classical Novae Explosions

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Abstract. The mechanism of classical novae explosions is explained, together with some of their observational properties. The scarce but not null impact of novae in the chemical evolution of the Milky Way is analyzed, as well as their relevance for the radioactivity in the Galaxy. A special emphasis is given to the predicted gamma-ray emission from novae and its relationship with the thermonuclear model itself and its related nucleosynthesis.

INTRODUCTION

Classical novae are a very common type of cosmic explosion. They occur very often in the Galaxy (∼35 yr⁻¹), although only ∼3-5 are discovered by amateur astronomers in the Galaxy every year. The explosion occurs on the top of white dwarfs accreting mass in a cataclysmic binary system and it is related to degenerate hydrogen ignition, leading to a thermonuclear runaway. Hydrogen burning occurs mainly through the CNO cycle, which operates out of equilibrium, because radioactive nuclei of lifetimes longer than the evolutionary timescale are synthesized. Convection also plays a crucial role, since it transports some of the β⁺-unstable nuclei synthesized to the outer envelope, where their subsequent decay powers the expansion of the envelope and the increase of luminosity.

Although classical novae release large amounts of energy (∼10⁴⁵ erg), they don’t have an impact in the interstellar medium dynamics, like supernovae. Concerning the chemical evolution of the Galaxy, they account only for ∼1/3000 of the Galactic disk’s gas and dust content; therefore, novae scarcely contribute to Galactic abundances, except for some particular elements, like ¹³C and ¹⁷O. Also, novae contribute to the radioactivity of the Galaxy, through the emission of γ-rays related to the decay of some medium and long-lived nuclei (i.e., ⁷Be, ²²Na and ²⁶Al).

Novae have been observed in all energy ranges, except in the γ-ray domain, where current instruments are not sensitive enough. From the observations in the optical,
ultraviolet and infrared, information about the physical conditions of the ejecta and its composition has been deduced. On the other hand, soft X-ray observations, when available, have provided some information about the turn-off of novae. A good example of a nova observed at all wavelengths is Nova Cyg 1992.

This paper has been organized as follows: first of all, some observational properties of classical novae are presented, mainly the light curves. Then, the thermonuclear runaway model is explained and illustrated with some numerical results. Finally, nucleosynthesis in classical novae and its relevance for the chemical evolution and the radioactivity of the Galaxy, with a special mention to theoretical models of $\gamma$-ray emission from novae, is presented.

**SOME OBSERVATIONAL PROPERTIES OF NOVAE**

Visual light curves of classical novae have some general trends that distinguish them from other variable stars, such as supernovae or dwarf novae, to cite two extreme examples. First of all, there is an increase in luminosity which corresponds to a decrease of $m_V$ (apparent visual magnitude) of more than 9 magnitudes occurring in a few days. In some cases, a pre-maximum halt, 2 magnitudes before maximum, has been observed (see [1] and references therein).

In order to characterize the nova light curves, their speed class is defined from either $t_2$ (or $t_3$), which is the time needed to decay in 2 (or 3) visual magnitudes after maximum. Novae speed classes range from very fast ($t_2 < 10$ days) and fast ($t_2 \sim 11 - 25$ days) to very slow ($t_2 \sim 151 - 250$ days) [2]. Nova Cyg 1992, for instance, had $t_2 \sim 12$ days, which is quite fast, and Nova Her 1991 was even faster ($t_2 \sim 2$ days). An example of a slow nova is Nova Cas 1993, which had $t_2 \sim 100$ days.

There is a relationship between the absolute magnitude at maximum $M_V$ and the speed class of novae, in the sense that brighter novae have shorter decay times ($t_2$ or $t_3$). The theoretical explanation of this relationship [3] is based on the widely accepted model of nova explosions, which shows that novae reach a luminosity at maximum which is close to the Eddington luminosity, and also that novae should eject roughly all their envelope in a time similar to $t_3$. Thus, one can establish quantitatively that $L_{\text{max}}$ is an increasing function of $M_{\text{wd}}$ and that $t_3$ is a decreasing function of $M_{\text{wd}}$. From these two relationships a new one can be obtained which relates $M_V$ at maximum with $t_3$. This empirical relation (which is valid both in the V and B photometric bands) is very often used to determine distances to novae, once visual extinction is known. Different calibrations of the maximum magnitude-rate of decline relationship (MMRD) exist, with that from [4] being the most usual one (see also [5]).

It is important to mention that it is in general assumed that two different kinds of nova populations exist [6]: the disk population (with scaleheight $z \lesssim 100$ pc) made of bright and fast novae, and the bulge population (with scaleheight up to $z \gtrsim 1$ kpc), made of dimmer and slower novae [7]. Also, Della Valle & Livio [8]
have established a link between these disk and thick-disk/bulge novae and the spectroscopic classification of Williams [9].

Since the launch of astronomical satellites and, specially, of the IUE (International Ultraviolet Explorer), light curves have been extended to other energetic domains away from the optical one. It was discovered from IUE observations of novae that the luminosity in the ultraviolet band increases when the optical one starts to decline: the reason is that there is a shift of the energy distribution to higher energies, because deeper and hotter regions of the expanding envelope are seen (the photosphere recedes because opacity decreases when temperature falls below 10^4K, the recombination temperature of hydrogen). Also, infrared observations when available (i.e., for novae in which dust forms) indicate an increase once the ultraviolet luminosity starts to decline, which is interpreted as the resulting reradiation by dust grains in the infrared of the ultraviolet energy they have absorbed. In summary, the bolometric luminosity of classical novae is constant for a quite long period of time, being the duration of this constant L_{bol} phase dependent on the remaining envelope mass of the nova.

The constancy of L_{bol} has been interpreted and obtained theoretically, although the concomitant mass-loss has not been well understood and modeled. The phase of constant L_{bol} corresponds to hydrostatic hydrogen burning in the remaining envelope of the nova, accompanied by a continuous mass-loss probably by an optically thick wind. Since the bolometric luminosity deduced from observations is close to or even larger than the Eddington luminosity, radiation pressure is probably the main force causing ejection of nova envelopes. An additional observational proof of this phase has come from the observations in the soft X-ray range. The EXOSAT satellite detected the nova GQ Mus (Nova Mus 1983) as a soft X-ray emitter (in the interval 0.04-2 keV), 460 days after optical maximum [10]. ROSAT detected again that source (0.1-2.4 keV), even 9 years after the explosion [11]. Nova Cyg 1992 was detected by ROSAT too as a powerful soft X-ray source, but the emission lasted in that case only for one year and a half [12]. The interpretation of the soft X-ray emission is that it is related to blackbody emission of the remaining hydrogen-burning shell, which becomes visible when the expanding envelope is transparent to it. The luminosity deduced is close to L_{Edd}, thus indicating again the constancy of L_{bol} and the hardening of the spectra. It is worth mentioning that in some novae (Nova Her 1991, Nova Pup 1991, Nova Vel 1999) hard X-ray emission has also been detected, with much smaller luminosities [13]. In these cases, the interpretation is different, since the emission mechanism is probably related to bremsstrahlung in some shocked region around the nova.

The observed turn-off times of novae, deduced from soft X-ray and ultraviolet observations, are between 1 and 5 yr [14], except for Nova Mus 1983 (9-10 yr). This is much shorter than expected from the nuclear burning timescale of the remaining envelope, thus telling that some extra mechanism besides of nuclear reactions leads to the extinction of the shell.

Spectra of novae are quite complicated and show different features related to some particular phases: four successive systems of absorption lines, and five overlapping
systems of emission lines are present in almost all novae. From the emission-line spectra in the nebular phase, both in the optical and the ultraviolet, and also from infrared spectra in some cases, detailed abundance determinations of nova ejecta are available (see [15] for a recent review). A general trend is observed: in many novae there is an enhancement of metallicities above solar and, in particular, enhancements of carbon-nitrogen-oxygen (CNO) elements and/or neon. It is known since long ago (see for instance [16] and [17]) that some enrichment of the accreted matter (which is in principle assumed to be of solar composition) with the underlying white dwarf core (of the CO or ONe type) is necessary, both to power the nova explosion and to explain the observed enhancements (see the following section for details).

THERMONUCLEAR RUNAWAY MODEL OF NOVA EXPLOSIONS

The accepted scenario of classical novae explosions is the thermonuclear runaway model, in which a cold white dwarf in a cataclysmic variable accretes hydrogen-rich matter, as a result of Roche lobe overflow of the main sequence companion. If the accretion rate is low enough (e.g., $\dot{M} \sim 10^{-9} - 10^{-10} M_\odot$ yr$^{-1}$), the accreted hydrogen is compressed up to degenerate conditions, thus leading to thermonuclear burning without control (thermonuclear runaway). The explosive burning of hydrogen produces some $\beta^+$-unstable nuclei of relatively short timescales (i.e., $^{13}$N, $^{14}$O, $^{15}$O, $^{17}$F), which are transported by convection to the outer envelope, where they are preserved from destruction until they decay. Their subsequent decay implies a huge liberation of energy in the outer shells, which originates envelope expansion, increase in luminosity and mass ejection, as required in a classical nova explosion.

In order to understand the thermonuclear runaway (TNR) mechanism for nova explosions, it is important to evaluate some relevant timescales (see [18] for a review). The accretion timescale, defined as $\tau_{\text{acc}} \sim \dot{M}_{\text{acc}}/\dot{M}$ (which is of the order of $10^4 - 10^5$ yr, depending on the accretion rate $\dot{M}$), the nuclear timescale $\tau_{\text{nuc}} \sim C_p T/\epsilon_{\text{nuc}}$ (which is as small as some seconds at peak burning), and the dynamical timescale ($\tau_{\text{dyn}} \sim H_p/c_s \sim (1/g)\sqrt{P/\rho}$). During the accretion phase, $\tau_{\text{acc}} \leq \tau_{\text{nuc}}$, accretion can proceed and increase the envelope mass. When degenerate ignition conditions are reached, degeneracy prevents envelope expansion and the TNR occurs. As temperature increases, degeneracy would be lifted (since $T$ would become larger than $T_{\text{Fermi}}$) and expansion would turn-off the explosion, but this is not so because $\tau_{\text{nuc}} \ll \tau_{\text{dyn}}$ (specially if the envelope is enriched in CNO elements above solar values, thus enhancing the contribution of the CNO cycle to hydrogen burning). Therefore, since the envelope can not respond by expanding, temperature and nuclear energy generation rate, $\epsilon_{\text{nuc}}$, continue to increase without control. The value of the nuclear timescale is crucial for the development of the TNR and its final fate. In fact there are mainly two types of nuclear timescales: those related to $\beta$-decays, $\tau_{\beta^+}$, and those related to proton capture reactions, $\tau_{(p,\gamma)}$. 
TABLE 1. Some properties of the explosions of CO and ONe novae

| Nova type | \( M_{\text{wd}} \) (M\(_{\odot}\)) | Peak temperature (K) | Kinetic energy of the ejecta \( M_{\text{ej}} \) (M\(_{\odot}\)) |
|-----------|-----------------------------------|----------------------|-------------------------------------------------|
| CO        | 1.15                              | \( 2.05 \times 10^8 \) | \( 1.1 \times 10^{45} \) | \( 1.3 \times 10^{-5} \) |
| ONe       | 1.15                              | \( 2.31 \times 10^8 \) | \( 1.5 \times 10^{45} \) | \( 2.6 \times 10^{-5} \) |
| ONe       | 1.25                              | \( 2.51 \times 10^8 \) | \( 1.5 \times 10^{45} \) | \( 1.8 \times 10^{-5} \) |

In the early evolution towards the TNR, \( \tau_{\beta^+} < \tau_{(p,\gamma)} \) and the CNO cycle operates in equilibrium. But as temperature increases up to \( \sim 10^8 \) K, the reverse situation is true (\( \tau_{\beta^+} \gtrsim \tau_{(p,\gamma)} \)), and thus the CNO cycle is \( \beta^- \)-limited. In addition, since the large energetic output produced by nuclear reactions can’t be evacuated only by radiation, convection sets in and transports the \( \beta^+ \)-unstable nuclei to the outer cooler regions where they are preserved from destruction and where they will decay later on (\( \tau_{\text{conv}} \lesssim \tau_{\beta^+} \)), leading to envelope expansion, increase in luminosity and final mass ejection if the attained velocities are large enough. Another important effect of convection is that it transports fresh unburned material to the burning shell. In summary, non-equilibrium burning occurs and the resulting nucleosynthesis will be far from that of hydrostatic hydrogen burning.

In table 1 we show some general properties of computed models, corresponding two carbon-oxygen (CO) and oxygen-neon (ONe) novae, with accretion rate \( 2 \times 10^{-10} \) M\(_{\odot}\) yr\(^{-1}\). More details about these models are given in [19]. Other recent detailed theoretical models of CO and ONe nova explosions are shown in [20] and [21], respectively.

NUCLEOSYNTHESIS IN NOVA EXPLOSIONS

The main goal of studies of nucleosynthesis in novae is, of course, to reproduce the observed abundances in novae ejecta. Although both from the observational and the theoretical side some uncertainties exist (different determinations of observed abundances or uncertain initial conditions for theoretical models), a quite good fit is obtained in many cases (see table 2, and more details in [19], together with the quoted papers in the table for the analyses of the observations and derivation of the abundances).

Chemical evolution of the Galaxy

In contrast with supernovae, novae are not important contributors to the abundances observed in the interstellar medium, but it is also true that they can contribute to Galactic abundances in some particular cases, when the overproduction factors with respect to solar abundances are larger than around \( 10^3 \) (see [19] and [15]). In figure 1 we show the overproduction factors relative to solar abundances versus mass number for two typical novae: a CO and an ONe ones, with mass \( 1.15 \) M\(_{\odot}\), 50% of mixing with core material and accretion rate \( 2 \times 10^{-10} \) M\(_{\odot}\) yr\(^{-1}\).
**FIGURE 1.** Overproduction factors, with respect to solar abundances, obtained for two nova models: a CO nova of $1.15 \, M_\odot$ with 50% mixing between accreted matter and core material (left), and an ONe nova of the same mass and degree of mixing (right).

**FIGURE 2.** Temporal evolution of the $\gamma$-ray emission of a CO (left) and an ONe (right) nova, of $1.15M_\odot$, at a distance of 1 kpc.
| Model                   | Element | V693 CrA 1981 | Vanlandingham et al. 1997 | ONe, 1.15M⊙, mixing 50% | ONe, 1.15M⊙, mixing 75% | Williams et al. 1985 | ONe, 1.25M⊙, mixing 50% | V1370 Aql 1982 | Andreà et al. 1994 | ONe, 1.35M⊙, mixing 75% | Snijders et al. 1987 | ONe, 1.35M⊙, mixing 75% | QU Vul 1984 | Austin et al. 1996 | ONe, 1.0M⊙, mixing 50% | Saizar et al. 1992 | ONe, 1.15M⊙, mixing 25% | PW Vul 1984 | Andreà et al. 1994 | CO, 1.15M⊙, mixing 25% | V1688 Cyg 1978 | Andreà et al. 1994 | CO, 1.15M⊙, mixing 25% | Stickland et al. 1981 | CO, 0.8M⊙, mixing 25% |
|------------------------|---------|---------------|---------------------------|--------------------------|--------------------------|-------------------------|-------------------------|-------------------|---------------------|---------------------------|-------------------------|--------------------------|---------------|-------------------|---------------------------|-----------------|--------------------------|-------------------|-------------------|---------------------------|-----------------|------------------|-------------------|
|                        | H       | 0.25          | 0.20                      | 0.025                    | 0.555                    | 0.068                   | 0.17                    | 0.058             | 0.32                | 0.30                      | 0.12                    | 0.12                     | 0.29           | 0.044             | 0.073                     | 0.053           | 0.073                    | 0.47           | 0.47             | 0.45                      | 0.45           | 0.45             |
|                        | He      | 0.43          | 0.51                      | 0.025                    | 0.045                    | 0.21                    | 0.14                    | 0.058             | 0.32                | 0.20                      | 0.13                    | 0.13                     | 0.32           | 0.10              | 0.14                     | 0.14            | 0.14                    | 0.28           | 0.23             | 0.22                      | 0.22           | 0.22             |
|                        | C       | 0.025         | 0.051                     | 0.025                    | 0.15                     | 0.30                    | 0.14                    | 0.12              | 0.28                | 0.049                     | 0.051                    | 0.051                     | 0.52           | 0.17              | 0.093                     | 0.14            | 0.14                    | 0.50           | 0.22             | 0.22                      | 0.22           | 0.22             |
|                        | N       | 0.055         | 0.45                      | 0.055                    | 0.15                     | 0.26                    | 0.14                    | 0.12              | 0.26                | 0.051                     | 0.051                    | 0.051                     | 0.50           | 0.24              | 0.039                     | 0.14            | 0.14                    | 0.75           | 0.18             | 0.22                      | 0.22           | 0.22             |
|                        | O       | 0.068         | 0.15                      | 0.15                     | 0.26                     | 0.030                   | 0.17                    | 0.28              | 0.26                | 0.28                     | 0.28                     | 0.28                     | 0.32           | 0.24              | 0.064                     | 0.17            | 0.17                    | 0.75           | 0.18             | 0.11                      | 0.11           | 0.11             |
|                        | Ne      | 0.17          | 0.18                      | 0.18                     | 0.24                     | 0.016                   | 0.17                    | 0.11              | 0.14                | 0.14                     | 0.14                     | 0.14                     | 0.50           | 0.24              | 0.065                     | 0.11            | 0.11                    | 0.75           | 0.18             | 0.14                      | 0.14           | 0.14             |
|                        | Na-Fe   | 0.058         | 0.065                     | 0.065                    | 0.065                     | 0.065                   | 0.065                   | 0.071             | 0.071               | 0.071                     | 0.071                     | 0.071                     | 0.50           | 0.062             | 0.062                     | 0.062           | 0.062                    | 0.75           | 0.062            | 0.062                      | 0.062          | 0.062            |
|                        | Z       | 0.32          | 0.50                      | 0.50                     | 0.50                     | 0.50                    | 0.50                    | 0.10              | 0.10                | 0.10                     | 0.10                     | 0.10                     | 0.50           | 0.50              | 0.50                     | 0.50            | 0.50                    | 0.75           | 0.50             | 0.50                      | 0.50           | 0.50             |

In this figure some general features are distinguishable: both in CO and in ONe novae, the largest yields correspond to elements of the CNO group, whether in CO novae Li is also largely overproduced. In the case of more massive ONe novae (i.e. 1.35 M⊙ [19]), intermediate-mass elements (such as Ne, Na, Mg, S, Cl) are also overproduced.

The origin of Galactic lithium (⁷Li) is still not completely understood. Although it is widely accepted that there is some primordial lithium produced during the big bang, and, of course, that spallation reactions by cosmic rays in the interstellar medium or in flares also produce it, some extra stellar source of ⁷Li (without generating ⁶Li) has to be invoked. The synthesis of ⁷Li in classical novae, by the beryllium transport mechanism [22], can produce large amounts of ⁷Li, but complete hydrodynamical models are needed in order to compute correctly the yields [23,24]. ⁷Li formation is favored in CO novae, with respect to ONe ones (see figure 1). The reason is that CO novae evolve faster (because of their larger ¹²C content), allowing photodisintegration of ⁸B through ⁸B(γ,p)⁷Be to prevent the destruction of the ⁷Be synthesized during the first part of the TNR (by means of ³He(α, γ)⁷Be). Large overproduction factors with respect to solar abundances are obtained (see
### TABLE 3. Main radioactive isotopes ejected by novae

| Isotope | Lifetime | Main disintegration process | Type of γ-ray emission | Nova type |
|---------|----------|----------------------------|------------------------|-----------|
| $^{13}$N | 862 s    | $\beta^+-$decay            | 511 keV line & continuum | CO and ONe |
| $^{18}$F | 158 min  | $\beta^+-$decay            | 511 keV line & continuum | CO and ONe |
| $^{7}$Be | 77 days  | $\epsilon^-$capture       | 478 keV line            | CO        |
| $^{22}$Na| 3.75 years | $\beta^+-$decay           | 1275 keV & 511 keV lines | ONe      |
| $^{26}$Al| $10^6$ years | $\beta^+-$decay         | 1809 keV & 511 keV lines | ONe      |

### TABLE 4. Ejected masses (in M$_\odot$) of radioactive nuclei obtained from theoretical models of CO and ONe novae ($^{13}$N and $^{18}$F 1 hr after peak temperature).

| Nova type | $M_{\text{wd}}$ (M$_\odot$) | $^{13}$N     | $^{18}$F     | $^{7}$Be      | $^{22}$Na     | $^{26}$Al     |
|-----------|-----------------------------|-------------|-------------|--------------|--------------|--------------|
| CO        | 1.15                        | $2.3 \times 10^{-8}$ | $2.6 \times 10^{-9}$ | $1.1 \times 10^{-10}$ | $3.8 \times 10^{-12}$ | $6.2 \times 10^{-10}$ |
| ONe       | 1.15                        | $2.9 \times 10^{-8}$ | $5.9 \times 10^{-9}$ | $1.6 \times 10^{-11}$ | $7.0 \times 10^{-9}$  | $2.1 \times 10^{-8}$  |
| ONe       | 1.25                        | $3.8 \times 10^{-8}$ | $4.5 \times 10^{-9}$ | $1.2 \times 10^{-11}$ | $6.3 \times 10^{-9}$  | $1.2 \times 10^{-8}$  |

figure 1), but classical novae can only account for roughly ~ 10% of the global Galactic $^7$Li [24]. It is important to stress that Romano et al. [25] have obtained (using our nova yields in a complete model of chemical Galactic evolution) that the contribution from novae is required in order to reproduce the shape of the growth of Li abundance versus metallicity.

Concerning the nuclei of the CNO group, the main isotopes produced in novae are $^{13}$C, $^{15}$N and $^{17}$O. The Galactic $^{17}$O is most probably almost entirely of novae origin [19]. Novae also contribute significantly to the Galactic $^{13}$C and $^{15}$N, but an extra source of $^{15}$N is required.

### Radioactivity in the Galaxy and γ-ray emission from novae

An important property of novae ejecta is the presence of radioactive nuclei (the role of novae as potential γ-ray emitters was mentioned long ago [26–28]).

Besides of the very short-lived isotopes responsible of the explosion itself (see above), there are other short, medium and long-lived nuclei which have some relevance for the radioactivity of the Galaxy and for the γ-ray emission of individual novae. A list of these nuclei with their main properties is displayed in table 3, whereas the ejected masses of them obtained from complete hydrodynamical models are shown in table 4. The short-lived nuclei $^{13}$N and $^{18}$F are produced in similar quantities in both nova types, whereas $^{7}$Be is mainly produced in CO novae (see the discussion on $^7$Li synthesis above) and $^{22}$Na and $^{26}$Al are produced in appreciable amounts only in ONe novae. The reason is that in nova explosions the temperatures reached (around $2 - 3 \times 10^8$ K, see table 1) are not high enough to break the CNO cycle; therefore, only if some seed nuclei (like $^{20}$Ne, $^{23}$Na, $^{24,25}$Mg) are present in the envelope material, can the NeNa-MgAl cycles operate and synthesize those radioactive nuclei (and other intermediate-mass isotopes). As CO white dwarfs are
devoid of these nuclei, it is almost impossible for them to produce large amounts of radioactive $^{22}\text{Na}$ and $^{26}\text{Al}$.

It is worth mentioning that uncertainties still affect some nuclear reaction rates of the NeNa-MgAl cycles; this leads to uncertain theoretical determinations of the yields of $^{22}\text{Na}$ and $^{26}\text{Al}$, but the error (from a purely nuclear point of view, and defined as the ratio between maximum and minimum productions) amounts to factors between 2 and 10 (see [29] for details). Also the final amount of $^{18}\text{F}$ synthesized in both CO and ONe novae is still not well known, since the nuclear reaction rates affecting $^{18}\text{F}$ destruction (via $^{18}\text{F}(p,\alpha)$ and $^{18}\text{F}(p,\gamma)$) are still not well determined [30].

Radioactive nuclei ejected by novae play a role in the radioactivity of the Galaxy which depends on their lifetimes. The short-lived nuclei (i.e., $^{13}\text{N}$ and $^{18}\text{F}$) produce an intense burst of $\gamma$-ray emission, with duration of some hours, which is emitted before the nova visual maximum (see [31,30] for details). This emission is related to positron annihilation, which consists of a line at 511 keV and a continuum at energies between 20 and 511 keV, related to the positronium continuum plus the comptonization of the photons emitted in the line. In figure 2 we show an example of the spectral evolution of a CO and an ONe nova, at different epochs after peak temperature.

The emission related to medium-lived nuclei, $^7\text{Be}$ and $^{22}\text{Na}$, appears later and is different in CO and ONe novae, because of their different nucleosynthesis. CO novae display a line at 478 keV, related to $^7\text{Be}$ decay, whereas ONe novae show a line at 1275 keV, related to $^{22}\text{Na}$ decay.

Finally, the long-lived isotope $^{26}\text{Al}$ is also produced by novae. The Galactic $\gamma$-ray emission observed at 1809 keV (Mahoney et al. [32] with the HEAO3 satellite; Diehl et al. [33] with the CGRO/COMPTEL) corresponds to the decay of $^{26}\text{Al}$. Its distribution seems to correspond better to that of a young population and the contribution of novae is not the dominant one (see [34,35]).

In summary, classical novae explosions produce $\gamma$-rays, being the signature of CO and ONe novae different. The detectability distances for the lines at 478 and 1275 keV with the future instrument INTEGRAL/SPI will range between 0.5 and 2 kpc. To compute these distances, the width of the lines is taken into account ($\sim 7$ keV for the 478 keV line and $\sim 20$ keV for the 1275 keV line). The continuum and the 511 keV line are the most intense emissions, but their appearance before visual maximum and their very short duration requires “a posteriori” analyses, with monitor-type instruments, with a large field-of-view and sensitivity up to some hundred keVs. With future instruments of these characteristics, novae would be detectable more easily in $\gamma$-rays than visually, because of the lack of extinction.

Future instrumentation in the $\gamma$ and hard X-ray domain will give crucial insights on the nova theory allowing for a direct confirmation of the nucleosynthesis in these explosions, but also providing unique information about the Galactic distribution of novae and their rates.
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