Nuclear Ashes: Reviewing Thirty Years of Nucleosynthesis in Classical Novae

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Abstract. One of the observational evidences in support of the thermonuclear runaway model for the classical nova outburst relies on the accompanying nucleosynthesis. In this paper, we stress the relevant role played by nucleosynthesis in our understanding of the nova phenomenon by constraining models through a comparison with both the atomic abundance determinations from the ejecta and the isotopic ratios measured in presolar grains of a likely nova origin. Furthermore, the endpoint of nova nucleosynthesis provides hints for the understanding of the mixing process responsible for the enhanced metallicities found in the ejecta, and reveals also information on the properties of the underlying white dwarf (mass, luminosity...).

We discuss first the interplay between nova outbursts and the Galactic chemical abundances: Classical nova outbursts are expected to be the major source of $^{13}$C, $^{15}$N and $^{17}$O in the Galaxy, and to contribute to the abundances of other species with $A < 40$, such as $^7$Li or $^{26}$Al. We describe the main nuclear path during the course of the explosion, with special emphasis on the synthesis of radioactive species, of particular interest for the gamma-ray output predicted from novae ($^7$Li, $^{18}$F, $^{22}$Na, $^{26}$Al). An overview of the recent discovery of presolar nova candidate grains, as well as a discussion of the role played by nuclear uncertainties associated with key reactions of the NeNa-MgAl and Si-Ca regions, are also given.

GALACTIC ALCHEMY: THE INTERPLAY BETWEEN NOVA OUTBURSTS AND THE GALACTIC ABUNDANCES

The high peak temperatures achieved during nova explosions, $T_{\text{peak}} \sim (2 - 3) \times 10^8$ K, suggest that abundance levels of the intermediate-mass elements in the ejecta must be significantly enhanced, as confirmed by spectroscopic determinations in well-observed nova shells. This raises the issue of the potential contribution of novae to the Galactic abundances, which can be roughly estimated as the product of the Galactic nova rate, the average ejected mass per nova outburst, and the Galaxy’s lifetime. This order of magnitude estimate points out that novae scarcely contribute to the Galaxy’s overall metallicity (as compared with other major sources, such as supernova explosions), nevertheless they can substantially contribute to the synthesis of some largely overproduced species (see Table 1, for a sample of publications addressing nucleosynthesis in classical novae). Hence, classical novae are likely sites for the synthesis of most of the Galactic $^{13}$C, $^{15}$N and $^{17}$O, whereas they can partially contribute to the Galactic abundances of other species with $A < 40$, such as $^7$Li, $^{19}$F, or $^{26}$Al [83, 39].

Overproduction factors, relative to solar, corresponding to hydrodynamic calculations
| Reference                          | Model category | Range of nuclei          |
|-----------------------------------|----------------|--------------------------|
| Arnould & Nørgaard (1975) [4]     | Parametric, 1 zone | $^3\text{He}$, $^7\text{Li}$, $\text{B}$, $\text{C}$, $\text{N}$, $\text{O}$ |
| Arnould et al. (1980) [5]         | Parametric, 1 zone | H-Ar                     |
| Boffin et al. (1993) [8]          | Parametric, 1 & 2 zones | $^3\text{He}$, $^7\text{Be}$, $^7\text{Li}$, $^8\text{B}$, $^9\text{C}$ |
| Coc et al. (1995) [13]            | Semianalytic, 1 zone | H-K                      |
| Coc et al. (2000) [14]            | Hydrodynamic, 1D | O, F                     |
| Glasner et al. (1997) [26]        | Hydrodynamic, 2D | H-F                      |
| Hernanz et al. (1996) [28]        | Hydrodynamic, 1D | $^3\text{He}$, $^7\text{Be}$, $^7\text{Li}$ |
| Hernanz et al. (1999) [29]        | Hydrodynamic, 1D | $^{13}\text{N}$, $^{18}\text{F}$ |
| Hillebrandt & Thielemann (1982) [32] | Parametric, 1 zone | H-Ar                     |
| Iliadis et al. (1999) [33]        | Parametric, 1 zone | H-Ca                     |
| José et al. (1997) [37]           | Hydrodynamic, 1D | Na, Mg, Al               |
| José & Hernanz (1997) [38]        | Hydrodynamic, 1D | H-Ca                     |
| José & Hernanz (1998) [39]        | Hydrodynamic, 1D | H-Ca                     |
| José et al. (1999) [40]           | Hydrodynamic, 1D | Ne-Na, Mg-Al             |
| José et al. (2001a) [41]          | Hydrodynamic, 1D | $^{13}\text{N}$, $^{18}\text{F}$, $^7\text{Be}$, $^{22}\text{Na}$, $^{26}\text{Al}$ |
| José et al. (2001b) [42]          | Hydrodynamic, 1D | C, N, O, Al, Mg, Si, Ne  |
| José et al. (2001c) [43]          | Hydrodynamic, 1D | Si-Ca                    |
| Kercek et al. (1998) [47]         | Hydrodynamic, 2D | H-F                      |
| Kercek et al. (1999) [48]         | Hydrodynamic, 3D | H-F                      |
| Kolb & Politano (1997) [49]       | Hydrodynamic, 1D | $^{22}\text{Na}$, $^{26}\text{Al}$ |
| Kovetz & Prialnik (1985) [50]     | Hydrodynamic, 1D | H-O                      |
| Kovetz & Prialnik (1997) [51]     | Hydrodynamic, 1D | H-O                      |
| Kudryashov & Tutukov (1995) [52]  | Parametric, 1 zone | H-Ar                     |
| Kudryashov et al. (2000) [53]     | Parametric, 1 zone | H-Ar                     |
| Lazareff et al. (1979) [54]       | Parametric, 2 zones | C, N, O, F, Ne           |
| Nofar et al. (1991) [56]          | Parametric, 1 zone | H-Al                     |
| Politano et al. (1995) [59]       | Hydrodynamic, 1D | H-Ca                     |
| Prialnik et al. (1978) [60]       | Hydrodynamic, 1D | H-O                      |
| Prialnik et al. (1979) [61]       | Hydrodynamic, 1D | H-O                      |
| Prialnik (1986) [62]              | Hydrodynamic, 1D | H-O                      |
| Prialnik & Shara (1986) [63]      | Hydrodynamic, 1D | H-Ne                     |
| Prialnik & Shara (1995) [64]      | Hydrodynamic, 1D | H-P                      |
| Shara & Prialnik (1994) [69]      | Hydrodynamic, 1D | H-Mg                     |
| Sparks et al. (1978) [73]         | Hydrodynamic, 1D | H-O                      |
| Starrfield et al. (1972) [74]     | Hydrodynamic, 1D | H-O                      |
| Starrfield et al. (1974a) [75]    | Hydrodynamic, 1D | H-O                      |
| Starrfield et al. (1974b) [76]    | Hydrodynamic, 1D | H-O                      |
| Starrfield et al. (1978a) [77]    | Hydrodynamic, 1D | $^3\text{He}$, $^7\text{Li}$, $\text{C}$, $\text{N}$, $\text{O}$ |
| Starrfield et al. (1978b) [78]    | Hydrodynamic, 1D | $^7\text{Li}$, $\text{C}$, $\text{N}$, $\text{O}$ |
| Starrfield et al. (1992) [80]     | Hydrodynamic, 1D | H-Ar                     |
| Starrfield et al. (1993) [81]     | Hydrodynamic, 1D | H-Ar                     |
| Starrfield et al. (1998) [83]     | Hydrodynamic, 1D | H-Ar                     |
| Starrfield et al. (2000) [84]     | Hydrodynamic, 1D | H-Ar                     |
| Starrfield et al. (2001) [85]     | Hydrodynamic, 1D | H-S                      |
| Vangioni-Flam et al. (1980) [87]  | Parametric, 1 zone | Ne, Al                   |
| Wallace & Woosley (1981) [89]     | Parametric, 1 zone | H-Al                     |
| Wanajo et al. (1999) [90]         | Semianalytic, 1 zone | H-Ca                     |
| Weiss & Truran (1990) [91]        | Parametric, 1 zone | H-Ca                     |
| Wiescher et al. (1986) [92]       | Parametric, 1 zone | H-Ar                     |
of nova outbursts on top of a 1.15 M$_\odot$ CO and a 1.35 M$_\odot$ ONe white dwarf, are shown in Figure 1. Because of the lower peak temperatures achieved in CO models, and also because of the lack of significant amounts of seed nuclei in the NeNa-MgAl region, the main nuclear activity in CO novae does not extend much beyond oxygen, as seen from the overproduction plot. In contrast, ONe models show a much larger nuclear activity, extending up to silicon (1.15 M$_\odot$ ONe) or argon (1.35 M$_\odot$ ONe). Hence, the presence of significantly large amounts of intermediate-mass nuclei in the spectra, such as phosphorus, sulfur, chlorine or argon, may reveal the presence of an underlying massive ONe white dwarf. Another trend derived from the analysis of the nucleosynthesis accompanying nova outbursts is the fact that the O/N and C/N ratios decrease as the mass of the white dwarf (and hence, the peak temperature attained during the explosion) increases.

**Abundance Determinations in the Ejecta from Novae**

In order to constraint the models, several works have focused on a direct comparison of the atomic abundances inferred from observations of the ejecta with the theoretical nucleosynthetic output (see [39, 83], and references therein). Despite of the problems associated with the modeling of the explosion [86], such as the unknown mechanism responsible for the mixing between the accreted envelope and the outermost shells of the underlying white dwarf [9, 21], or the difficulties to eject as much material as inferred from observations [71], there is an excellent agreement between theory and observations.
as regards nucleosynthesis (i.e., including atomic abundances -H, He, C, O, Ne, Na-Fe-, and a plausible endpoint for nova nucleosynthesis). In some cases, such as for PW Vul 1984, the agreement between observations and theoretical predictions (see [39], Table 5, for details) is really overwhelming. The reader is referred to [24] for an extended list of abundance determinations in the ejecta from novae, and to [68, 88] for recent efforts to improve the abundance pattern for QU Vul 1984 and V1974 Cyg 1992, respectively.

Since the nuclear path is very sensitive to details of the evolution (chemical composition, extent of convective mixing, thermal history of the envelope...), the agreement between inferred abundances and theoretical yields not only validates the thermonuclear runaway model, but also poses limits on the (yet unknown) mixing mechanism itself: for instance, if mixing occurs very late in the course of the explosion, the accumulation of larger amounts of matter in the envelope will be favored (since the injection of significant amounts of the triggering nucleus $^{12}$C will be delayed). Hence, one would expect to end up with a more violent outburst, characterized by a higher $T_{\text{peak}}$, exceeding in some cases $4 \times 10^8$ K, and, as a result, a significant enrichment in heavier species, beyond calcium, in the ejecta from novae involving very massive white dwarfs, a pattern never observed so far.

**Presolar Grains: Gifts from Heaven**

Infrared [22, 24] and ultraviolet observations [70] of the temporal evolution of nova light curves suggest that novae form grains in the expanding nova shells. Both CO and ONe novae behave similarly in the infrared right after the outburst. However, as the ejected envelope expands and becomes optically thin, such behavior dramatically changes: CO novae are typically followed by a phase of dust formation corresponding to a decline in visual light, together with a simultaneous rise in the infrared emission [23, 25]. In contrast, it has been argued that ONe novae (that involve more massive white dwarfs than CO novae) are not so prolific producers of dust as a result of the lower mass, high-velocity ejecta, where the typical densities can be low enough to enable the condensation of appreciable amounts of dust. Hints on the condensation of dust containing silicates, silicon carbide, carbon and hydrocarbons have been reported from a number of novae (see [24] for a recent review).

Up to now, the identification of presolar nova grains, presumably condensed in the shells ejected during the explosion, relied only on low $^{20}$Ne/$^{22}$Ne ratios (attributed to $^{22}$Na decay), but quite recently five silicon carbide and two graphite grains that exhibit isotopic signatures characteristic of nova nucleosynthesis have been identified [1, 2]. They are characterized by very low $^{12}$C/$^{13}$C and $^{14}$N/$^{15}$N ratios, $^{30}$Si excesses and close-to- or slightly lower-than-solar $^{29}$Si/$^{28}$Si ratios, high $^{26}$Al/$^{27}$Al ratios (determined only for two grains) and low $^{20}$Ne/$^{22}$Ne ratios (only measured in the graphite grain KFB1a-161). Such a promising discovery provides a much valuable source of constraint for nova nucleosynthesis (since contrary to the atomic abundance determinations derived from nova ejecta, measurements provide more accurate isotopic ratios) and opens interesting possibilities for the future.

Theoretical isotopic ratios for a variety of nuclear species, ranging from C to Si, based
SYNTHESIS OF RADIOACTIVE NUCLEI DURING NOVA OUTBURSTS

Among the isotopes synthesized during classical nova outbursts, several radioactive species deserve a particular attention. Short-lived nuclei, such as $^{14,15}$O and $^{17}$F (and to some extent $^{13}$N) have been identified as the key isotopes that power the expansion and further ejection during a nova outburst through a sudden release of energy, a few minutes after peak temperature [74]. Other isotopes have been extensively investigated in connection with the theoretical gamma-ray output from novae [11, 12, 55]. Hence, $^{13}$N and $^{18}$F are responsible for the predicted prompt $\gamma$-ray emission [29] at and below 511 keV, whereas $^{7}$Be and $^{22}$Na [27], which decay much later, when the envelope is optically thin, are the sources that power line emission at 478 and 1275 keV, respectively. $^{26}$Al is another important radioactive isotope that can be synthesized during nova outbursts, although only its cumulative emission can be observed because of its slow decay.

We will briefly focus on the corresponding nuclear paths leading to the synthesis of the abovementioned gamma-ray emitters, with special emphasis on the nuclear uncertainties associated with the relevant reaction rates. We refer the reader to [30] for a review of the current theoretical predictions of the gamma-ray output from novae and of the chances for a nearby future detection using spacecrafts such as INTEGRAL (see also [31]). As for a comprehensive summary of the main uncertainties affecting nuclear reaction rates for nova temperatures, the reader is referred to [15]. Other recent attempts to fully analyze the impact of nuclear physics uncertainties in nova nucleosynthesis involve parametric one-zone calculations with temperature and density profiles extracted from hydrodynamic models [34, 35], as well as Monte Carlo simulations [72]. We would like to stress, however, that results based on parametric calculations usually tend to overestimate the effect of a given reaction rate uncertainty, as compared with the outcome from hydrodynamic tests. Hence, although these simplified techniques provide a very valuable tool to potentially identify key reactions through an extraordinary large number of tests, final conclusions have to be confirmed through hydrodynamic calculations.

$^7$Be-$^7$Li

$^3$He$(\alpha, \gamma)^7$Be is the main reaction leading to $^7$Be synthesis (with $^3$He coming from both the accreted amount plus the contribution in place from $^1$H(p,e$^+$ $\nu$e)$^2$H(p,$\gamma$)$^3$He), which is transformed into $^7$Li by means of an electron capture, emitting a $\gamma$-ray photon of 478 keV [27].

Its production in classical nova outbursts has been very controversial. Results from the first pioneering calculation, in the framework of a simple parametric model [4], were confirmed by early hydrodynamic simulations [77], assuming however an enve-
lope in-place (the first hydrodynamic nova models that properly included the onset of the accretion phase were not available until the 80s), thus neglecting the impact of the accretion phase on the evolution. These results were refuted later on, in terms of parametric one/two zone models [8], pointing out the critical role played by the $^9\text{C}(p,\gamma)$ reaction, not included in all previous works (i.e., [4, 77]), and claiming therefore for an unlikely synthesis of $^7\text{Li}$ in novae. The scenario was recently revisited by [28, 39], who performed new hydrodynamic calculations, taking into account both the accretion and explosion stages, and a full reaction network (including $^9\text{C}(p,\gamma)$). These studies confirmed that the Be-transport mechanism [10] is able to produce a large overproduction of $^7\text{Li}$ in nova explosions.

Among the issues that affect $^7\text{Li}$ synthesis in novae, one the most critical ones is the final amount of $^3\text{He}$ that survives the early rise in temperature when the thermonuclear runaway ensues. In particular, the different timescales to reach $T_{\text{peak}}$ achieved for CO and ONe novae, which deeply depend on the initial $^{12}\text{C}$ content in the envelope, lead to a larger amount of $^7\text{Be}$ in CO novae (which survives destruction through $^7\text{Be}(p,\gamma)^8\text{B}$ because of the very efficient inverse photodisintegration reaction on $^8\text{B}$). No relevant nuclear uncertainties in the domain of nova temperatures affect the corresponding reaction rates.

The puzzling $^7\text{Li}$ synthesis in novae, suggested for many years but elusive up to now, has been apparently confirmed for the first time in the spectra of V382 Vel (Nova Velorum 1999) [18], for which an observed feature compatible with the doublet at 6708 Å of LiI has been reported. Although this identification is not yet confirmed (there is no unambiguous interpretation for such a feature), the lithium abundances inferred are fully compatible with the theoretical upper limits given for a fast nova (i.e., [28, 39]).

The potential contribution of classical novae to the Galactic $^7\text{Li}$ content turns out to be rather small (i.e., less than 15%), even if the $^7\text{Li}$ yield from the most favorable case, a massive CO nova [28], is considered. Nevertheless, a nova contribution is required to match the $^7\text{Li}$ content in realistic calculations of Galactic chemical evolution [66, 67].

$^{22}\text{Na}$

The potential role of $^{22}\text{Na}$ for diagnosis of nova outbursts was first suggested by [11]. It decays to a short-lived excited state of $^{22}\text{Ne}$ (with a lifetime of $\tau = 3.75$ yr), which de-excites to its ground state by emitting a $\gamma$-ray photon of 1.275 MeV. Through this mechanism, nearby ONe novae within a few kiloparsecs from the Sun may provide detectable $\gamma$-ray fluxes [30]. Several experimental verifications of this $\gamma$-ray emission at 1.275 MeV from nearby novae have been attempted in the last twenty years, using balloon-borne experiments and detectors on-board satellites such as HEAO-3, SMM, or CGRO, from which upper limits on the ejected $^{22}\text{Na}$ have been derived. In particular, the observations performed with the COMPTEL experiment on-board CGRO of five recent Ne-type novae [36], as well as observations of standard CO novae, have led to an upper limit of $3.7 \times 10^{-8}$ M$_\odot$ for the $^{22}\text{Na}$ mass ejected by any nova in the Galactic disk. A limit that poses some constraints on pre-existing theoretical models of classical nova explosions.
Synthesis of $^{22}\text{Na}$ in novae, extensively investigated in the last two decades [32, 92, 94, 91, 58, 59, 13, 52, 49, 39, 83, 40, 90, 53, 84, 41, 85], proceeds through different reaction paths. In the $^{20}\text{Ne}$-enriched envelopes of ONe novae [40], it takes place through $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$, followed either by another proton capture and a $\beta^+$-decay into $^{22}\text{Na}$ (i.e., $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}(\beta^+)^{22}\text{Na}$), or decaying first into $^{21}\text{Ne}$ before another proton capture ensues (i.e., $^{21}\text{Na}(\beta^+)^{21}\text{Ne}(p,\gamma)^{22}\text{Na}$). Other potential channels, such as proton captures on the seed nucleus $^{23}\text{Na}$, play only a marginal role on $^{22}\text{Na}$ synthesis because of the much higher initial $^{20}\text{Ne}$ content in such ONe models. As for the main destruction channel at nova temperatures, $^{22}\text{Na}(p,\gamma)^{23}\text{Mg}$ competes favorably with $^{22}\text{Na}(\beta^+)^{22}\text{Ne}$. Nuclear uncertainties strongly affect the rates for $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}$ and $^{22}\text{Na}(p,\gamma)^{23}\text{Mg}$ [40], which translate into an uncertainty in the final $^{22}\text{Na}$ yields (and ultimately on the maximum detectability distance of the 1275 keV line expected from nova outbursts). Advances to reduce the uncertainty affecting the $^{21}\text{Na}(p,\gamma)$ rate have been recently achieved with the DRAGON recoil separator facility at TRIUMF [57, 7].

$^{26}\text{Al}$

Several isotopes should be considered as potential seeds for $^{26}\text{Al}$ synthesis: in particular, $^{24,25}\text{Mg}$ and to some extent $^{23}\text{Na}$ and $^{20,22}\text{Ne}$ [37]. The main nuclear reaction path leading to $^{26}\text{Al}$ synthesis, also investigated in a large number of papers [54, 5, 32, 17, 92, 94, 91, 56, 58, 69, 59, 13, 52, 49, 39, 83, 40, 90, 53, 84, 41, 85], is given by $^{24}\text{Mg}(p,\gamma)^{25}\text{Al}(\beta^+)^{25}\text{Mg}(p,\gamma)^{26}\text{Al}$, whereas destruction is dominated by $^{26}\text{Al}^8(p,\gamma)^{26}\text{Si}$. A significant nuclear uncertainty affects the $^{25}\text{Al}(p,\gamma)^{26}\text{Si}$ rate [40], which translates into an uncertainty in the expected contribution of novae to the Galactic $^{26}\text{Al}$ content. A critical issue in order to estimate this contribution is the initial composition of the ONe white dwarf. Whereas calculations by Starrfield et al. [79, 83, 84, 85] assume a core composition based on hydrostatic models of carbon burning nucleosynthesis [3], rather enriched in $^{24}\text{Mg}$ (with a ratio $^{16}\text{O}^{20}\text{Ne}^{24}\text{Mg}$ around 1.5:2.5:1), we adopt more recent values taken from stellar evolution calculations of intermediate-mass stars [65], for which the $^{24}\text{Mg}$ content is much smaller ($^{16}\text{O}^{20}\text{Ne}^{24}\text{Mg}$ is 10:6:1). Calculations based on the new ONe white dwarf composition [37, 39, 40, 41], suggest that the contribution of novae to the Galactic $^{26}\text{Al}$ abundance is rather small (i.e., less than 15%), in good agreement with the results derived from the COMPTEL map of the 1809 keV $^{26}\text{Al}$ emission in the Galaxy (see [20]), which points towards young progenitors (type II supernovae and Wolf-Rayet stars).

$^{18}\text{F}$

The predicted gamma-ray emission from novae at and below 511 keV at early epochs after the explosion is basically driven by the amount of $^{18}\text{F}$ present in the envelope [55, 27, 29]. The synthesis of $^{18}\text{F}$ is powered by $^{16}\text{O}(p,\gamma)^{17}\text{F}$, followed either by $^{17}\text{F}(p,\gamma)^{18}\text{Ne}(\beta^+)^{18}\text{F}$ or by $^{17}\text{F}(\beta^+)^{17}\text{O}(p,\gamma)^{18}\text{F}$. The dominant destruction chan-
nel is $^{18}\text{F}(p,\alpha)^{15}\text{O}$ plus a minor contribution from $^{18}\text{F}(p,\gamma)^{19}\text{Ne}$. The effect of the nuclear uncertainties associated with some of the rates (i.e., $^{18}\text{F}(p,\alpha)^{15}\text{O}$, $^{18}\text{F}(p,\gamma)^{19}\text{Ne}$, $^{17}\text{O}(p,\alpha)^{14}\text{N}$ and $^{17}\text{O}(p,\gamma)^{18}\text{F}$) [29, 14, 15] is, in this case, quite remarkable: they translate into a large uncertainty in the expected $^{18}\text{F}$ yield, and therefore, in the corresponding gamma-ray flux and maximum detectability distance. Advances to reduce this uncertainty have been reviewed during the Classical Nova Conference [6, 19] and elsewhere [16], and involve several nuclear physics experiments performed in Oak Ridge (USA) and Orsay (France).

The endpoint of nova nucleosynthesis

In agreement with the chemical pattern derived from detailed observations of the ejecta, the theoretical endpoint for nova nucleosynthesis is limited to $A < 40$ (i.e., calcium), in agreement with current theoretical nucleosynthetic estimates, provided that the temperatures attained in the envelope during the explosion remain limited to $T_{\text{peak}} \sim (2-3) \times 10^8$ K.

The nuclear activity in the Si-Ca region has been scarcely analyzed in detail in the context of classical nova outbursts [83, 33, 90, 43]. It is powered by a leakage from the NeNa-MgAl region, where the activity is confined during the early stages of the explosion. The main reaction that drives the nuclear activity towards heavier species (i.e., beyond S) is mainly $^{30}\text{P}(p,\gamma)^{31}\text{S}$, either followed by $^{31}\text{S}(p,\gamma)^{32}\text{Cl}(\beta^+)^{32}\text{S}$, or by $^{31}\text{S}(\beta^+)^{31}\text{P}(p,\gamma)^{32}\text{S}$ [43]. The $^{30}\text{P}(p,\gamma)$ rate is based only on Hauser-Feshbach estimates, which can be rather uncertain at the domain of nova temperatures. To test the effect of this uncertainty on the predicted yields, we have performed a series of hydrodynamic calculations [43], modifying arbitrarily the nominal rate. Hence, for a high $^{30}\text{P}(p,\gamma)$ rate (i.e., 100 times the nominal one), the final $^{30}\text{Si}$ yields are dramatically reduced by a factor of 30, whereas for a low $^{30}\text{P}(p,\gamma)$ rate (i.e., 0.01 times the nominal one), the final $^{30}\text{Si}$ yields are slightly increased by a factor of 5, whereas isotopes above silicon are reduced by a factor of $\sim 10$, with dramatic impact on theoretical estimates involving both the composition of the ejecta and of presolar grains.

The impact of nuclear reaction rate uncertainties on nucleosynthesis calculations points out the need of accurate nuclear physics inputs, and stresses the role played by classical novae as perfect laboratories for nuclear astrophysics.

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