PROCEEDINGS OF SCIENCE

Classical vs. primordial nova explosions

Jordi José[*]

Dept. Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya (UPC), Sor Eulàlia d'Anzizu s/n, Campus Nord UPC, Mòdul B4-B5, 2ª planta, E-08034 Barcelona, Spain, and Institut d'Estudis Espacials de Catalunya (IEEC)

E-mail: `jordi.jose@upc.edu`

Margarita Hernanz

Institut de Ciències de l'Espai (CSIC), Facultat de Ciències, Campus UAB, Torre C5-parell, 2ª planta, E-08193 Bellaterra (Barcelona), Spain, and Institut d'Estudis Espacials de Catalunya (IEEC)

E-mail: `hernanz@ieec.uab.es`

Enrique García-Berro, & Pilar Gil-Pons

Dept. Física Aplicada, Universitat Politècnica de Catalunya (UPC), Av. del Canal Olímpic s/n, E-08860 Castelldefels (Barcelona), Spain, and Institut d'Estudis Espacials de Catalunya (IEEC)

E-mail: `garcia@fa.upc.edu; pilar@fa.upc.edu`

Classical nova outbursts are powered by thermonuclear runaways (hereafter, TNRs) that take place in the hydrogen-rich accreted envelopes of white dwarf stars in close binary systems. Extensive numerical simulations of nova outbursts have shown that the accreted envelopes reach peak temperatures ranging between 100 and 400 MK, for about several hundred seconds, and therefore, their ejecta is expected to show signatures of a significant nuclear activity. Indeed, it has been claimed that novae can play a certain role in the enrichment of the interstellar medium through a number of intermediate-mass elements. This includes ^{17}O, ^{15}N, and ^{13}C, systematically overproduced in huge amounts with respect to solar abundances, with a lower contribution in a number of other species with A < 40, such as ^{7}Li, ^{19}F, or ^{26}Al. Estimates of the contribution of novae to the Galactic abundances usually rely on poorly known quantities, and implicitly assume that novae have been the same sort of objects during the whole Galaxy's history. In this paper, we review our understanding of classical novae and outline our current strategies to simulate *primordial* (Population III) nova outbursts.

International Symposium on Nuclear Astrophysics – Nuclei in the Cosmos – IX
CERN, Geneva, Switzerland
25-30 June, 2006

---

[*] Speaker

PoS(NIC-IX)034

1. Introduction

Classical novae are stellar explosions that have captivated the interest of astronomers since ancient times. They are characterized by a sudden rise in optical brightness (from 8 to 18 magnitudes in 1 or 2 days), with peak luminosities reaching 10^4 – 10^5 L_o. During these cataclysmic events, 10^{-4} – 10^{-5} M_o are ejected into the interstellar medium, at typical velocities ranging from 10^2 – 10^3 km s^{-1}. The nature of nova explosions involves a cataclysmic binary system, consisting of a compact, white dwarf star (which is CO or ONe-rich) and a low mass companion (typically, a K or M dwarf, of solar composition). The system is close enough (orbital periods < 10 – 12^{hrs}), allowing mass transfer episodes caused by Roche Lobe overflow of the Main Sequence companion star. The flow of hydrogen-rich material forms an accretion disk that surrounds the white dwarf and ultimately accumulates on its surface (at a rate M ~ 10^{-9} -10^{-10} $M_o.yr^{-1}$), building up an envelope in semi-degenerate conditions until a violent thermonuclear runaway (hereafter, TNR) ensues.

2. Nucleosynthesis in classical novae

The early evolution of the TNR is dominated by the operation of both the proton-proton chains as well as the *cold* CNO cycle (mainly through $^{12}C(p,\gamma)^{13}N(\beta^+)^{13}C(p,\gamma)^{14}N$). As shown in Fig. 1, the dominant nuclear reaction flow proceeds close to the valley of stability and is dominated by (p,γ), (p,α), and β^+-decays. It is worth noting that neutron and alpha-capture reactions are completely negligible in the physical conditions that characterize a classical nova. Models of nova nucleosynthesis point towards a nucleosynthetic endpoint around Ca, in agreement with observations of nova shells. In fact, and despite of the problems associated with the modeling of nova outbursts (mainly, the nature of the mixing process and the discrepancy in the amount of mass ejected between models and observations; see Starrfield et al. 1998), there is, in general, good agreement between the abundance patterns inferred from observations and those derived from numerical hydro calculations (see Table 1, for details).

Indeed, there is a lack of consensus concerning the nature of the mixing process (that, according to Table 1, should be able to account for metallicities as high as 0.86 in the ejecta), but the specific properties of the outermost layers of the white dwarf, where the mixing with solar-like accreted material will take place, will certainly have a dramatic influence in the explosion. In fact, one of the most critical quantities at the beginning of the TNR is the amount of ^{12}C present at the base of the envelope: the triggering reaction of the TNR is $^{12}C(p,\gamma)$, which not only determines the amount of mass accreted in the envelope, but also the proper pressure at the envelope's base, which in turn, determines the strength of the outburst (i.e., peak temperature, mass and velocity of the ejected shells...). The existence of two distinct nova classes, hosting CO and ONe white dwarfs, observationally confirmed by the measurement of strong neon lines in some novae (Aql 1982, Cyg 1992...) posed interesting questions concerning the previous evolution of the progenitor system. As shown in José et al. (2003), the layers of unburnt material from previous evolutionary stages that surround the white dwarf core may have an imprint in the resulting nova nucleosynthesis if accretion settles on top of the white dwarf before these shells are lost. One of the most striking implications from this study is the possibility of misclassification of classical novae, since some explosions hosting ONe cores surrounded by CO 'buffer' layers will not show any evidence of neon and may be (wrongly?) identified as non-neon (i.e., CO) novae.

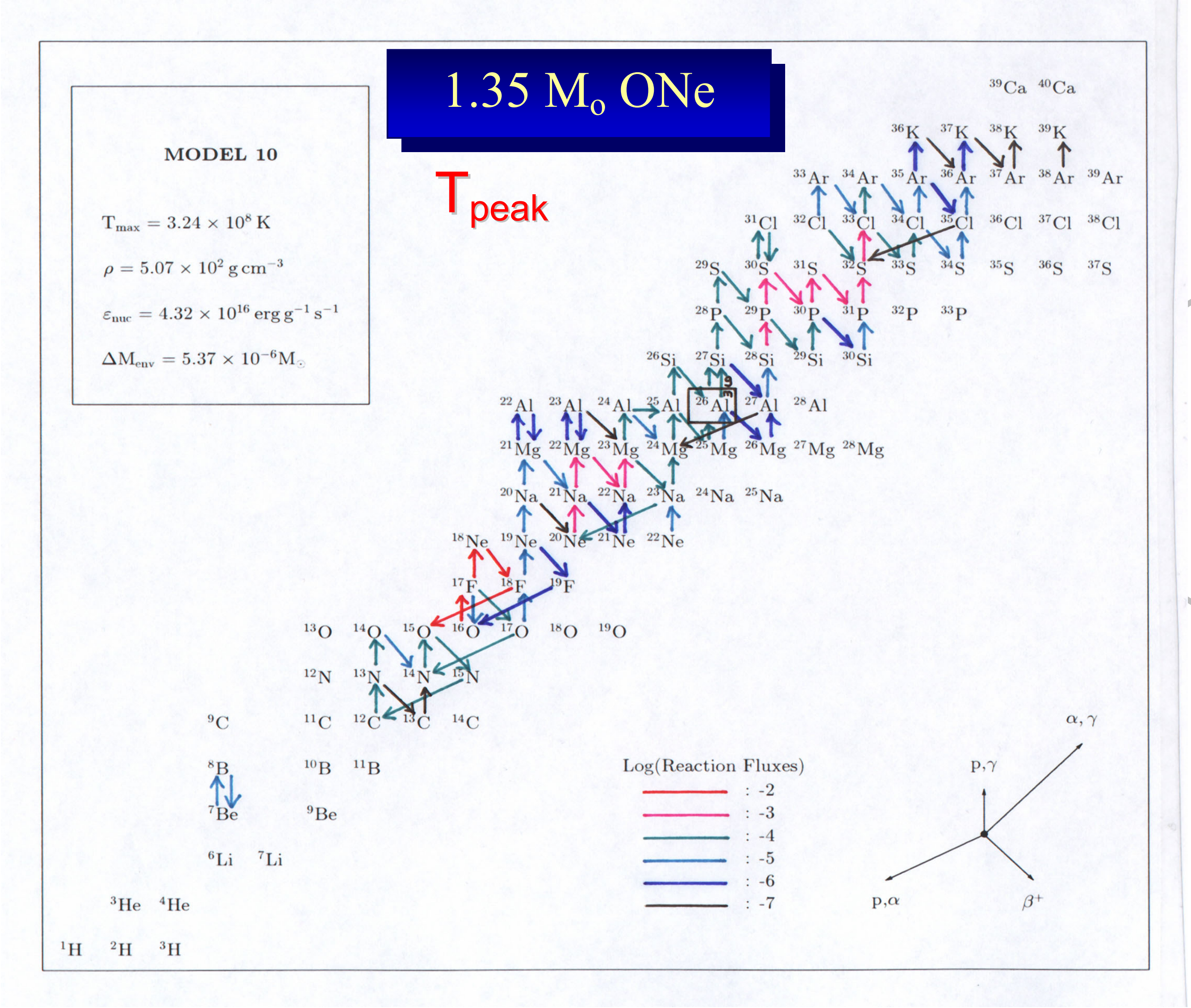

Fig. 1: Main nuclear reaction fluxes (number of reactions per unit volume and time) at peak temperature for a nova outburst on a 1.35 M$_o$ ONe white dwarf.

One of the topics of interest associated with nova nucleosynthesis is their potential contribution to the Galactic abundances. A number of hydrodynamic simulations have suggested that ^{17}O, ^{15}N, and to some extent ^{13}C, may be significantly overproduced in nova outbursts (Gehrz et al. 1998; José & Hernanz 1998), together with a non negligible contribution (i.e., 15-20% of the Galactic values) in a number of isotopes of astrophysical relevance, such as

^{7}Li (Starrfield et al. 1978; Hernanz et al. 1996), or ^{26}Al (José et al. 1997; Starrfield et al. 1998), to quote a few.

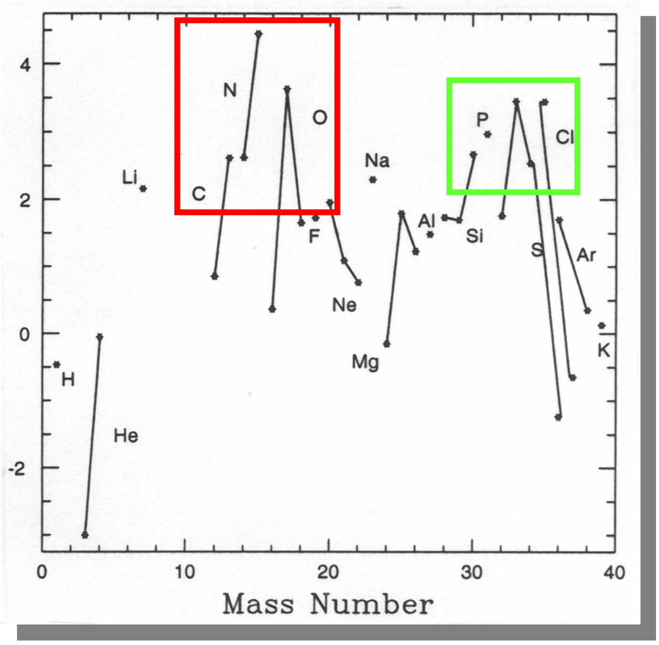

Fig. 2: Overproduction factors relative to solar in the mean ejected material of a nova outburst, for a 1.35 M_o ONe white dwarf.

	H	He	C	N	O	Ne	Na-Fe	Metallicity
V693 CrA 1981								
Vanlandingham et al. 1997	0.25	0.43	0.025	0.055	0.068	0.17	0.058	0.32
Model ONe3	0.30	0.20	0.051	0.045	0.15	0.18	0.065	0.50
Andreä et al. 1994	0.16	0.18	0.0078	0.14	0.21	0.26	0.030	0.66
Model ONe4	0.12	0.13	0.049	0.051	0.28	0.26	0.10	0.75
Williams et al. 1985	0.29	0.32	0.0046	0.080	0.12	0.17	0.016	0.39
Model ONe5	0.28	0.22	0.060	0.074	0.11	0.18	0.071	0.50
V1370 Aql 1982								
Andreä et al. 1994	0.044	0.10	0.050	0.19	0.037	0.56	0.017	0.86
Model ONe7	0.073	0.17	0.051	0.18	0.14	0.24	0.14	0.76
Snijders et al. 1987	0.053	0.088	0.035	0.14	0.051	0.52	0.11	0.86
Model ONe7	0.073	0.17	0.051	0.18	0.14	0.24	0.14	0.76
QU Vul 1984								
Austin et al. 1996	0.36	0.19		0.071	0.19	0.18	0.0014	0.44
Model ONe1	0.32	0.18	0.030	0.034	0.20	0.18	0.062	0.50
Saizar et al. 1992	0.30	0.60	0.0013	0.018	0.039	0.040	0.0049	0.10
Model ONe2	0.47	0.28	0.041	0.047	0.037	0.090	0.0035	0.25
PW Vul 1984								
Andreä et al. 1994	0.47	0.23	0.073	0.14	0.083	0.0040	0.0048	0.30
Model CO4	0.47	0.25	0.073	0.094	0.10	0.0036	0.0017	0.28
V1688 Cyg 1978								
Andreä et al. 1994	0.45	0.22	0.070	0.14	0.12			0.33
Model CO4	0.47	0.25	0.073	0.094	0.10	0.0036	0.0017	0.28
Stickland et al. 1981	0.45	0.23	0.047	0.14	0.13	0.0068		0.32
Model CO1	0.51	0.21	0.048	0.096	0.13	0.0038	0.0015	0.28

Table 1: Comparison between atomic abundances inferred from observations of nova shells and theoretical predictions from hydrodynamic simulations (José & Hernanz 1998).

It is worth noting that this kind of estimates suffers from a large uncertainty since both the mean ejected mass per nova outburst and the nova rate during the overall Galaxy's lifetime are not well known quantities. The fraction of ONe novae over the total Galactic nova rate, critical to evaluate the contribution of novae to the Galactic ^{26}Al, for instance, has been recently revisited, taking into account the effect of binarity (see Gil-Pons et al. 2003 for details).

There are reasons to believe that contemporary (classical) novae are not the same sort of objects than those evolved in the most *primitive,* Population III cataclysmic binaries, the reason being the specific composition of the Main Sequence companion star. It is likely that a nova outburst begins with the transfer of material from the accretion disk (whose composition reflects that of the companion star), accumulating on top of the 'naked' white dwarf in semi-degenerate conditions. This paves the road for a TNR. Numerical simulations show that the amount of ^{12}C in solar-like material is enough to trigger a mild TNR but accretion of extremely metal poor material (as expected in a Population III binary) certainly may lead to a different kind of explosion. It is our aim to tackle the study of accretion in such primordial binaries for a wide range of values of the parameter space. Preliminary results show remarkably different nucleosynthetic imprints between classical and primordial novae. A thorough analysis of these peculiar nova explosions will be soon published elsewhere.

References

[1] R.D. Gehrz, J.W. Truran, R.E. Williams, & S. Starrfield, *Nucleosynthesis in classical novae and its contribution to the interstellar medium, PASP* **110** (1998), 3.

[2] P. Gil-Pons, E. García-Berro, J. José, M. Hernanz, & J.W. Truran, *The frequency of occurrence of novae hosting an ONe white dwarf, A&A* **407** (2003), 1021.

[3] M. Hernanz, J. José, A. Coc, & J. Isern, *On the synthesis of ^{7}Li and ^{7}Be in novae, ApJ* **465** (1996), L27.

[4] J. José, J., & M. Hernanz, *Nucleosynthesis in classical novae: CO vs. ONe white dwarfs*, *ApJ* **494** (1998), 680.

[5] J. José, J., M. Hernanz, & A. Coc, *New results on ^{26}Al production in classical novae, ApJ* **479** (1997), L55.

[6] J. José, J., M. Hernanz, E. García-Berro, & P. Gil-Pons, *The impact of the chemical stratification of white dwarfs on the classification of classical novae, ApJ* **597** (2003), L41.

[7] S. Starrfield, J.W. Truran, W.M. Sparks, & M. Arnould, *On ^{7}Li production in nova explosions, ApJ* **222** (1978), 600.

[8] S. Starrfield, J.W. Truran, M.C. Wiescher, & W.M. Sparks, *Evolutionary sequences for Nova V1974 Cygni using new nuclear reaction rates and opacities, MNRAS* **296** (1998), 502.

PoS(NIC-IX)034