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Absorption and emission features of ^{7}Be II in the outburst spectra of V838 Her (Nova Her 1991)

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ABSTRACT

High- and low-resolution *International Ultraviolet Explorer* (*IUE*) spectra of V838 Her in the early outburst stages exhibit a strong absorption feature shortward of λ3130. We discuss the nature of this spectral feature and provide convincing evidence that it corresponds to the blueshifted resonance doublet of singly ionized ^{7}Be recently discovered in other novae. During the evolution of the outburst the appearance of an emission feature close to λ3130 Å is also identified as ^{7}Be II λ3132 because the usual identification as the O III λ3133.7 Bowen fluorescence line is hardly compatible with both the known oxygen underabundance in the nova ejecta and the low optical depths in the nebula due to the high outflow velocity. The average ^{7}Be abundance relative to hydrogen, estimated by four different methods, i.e. the ^{7}Be II/Mg II absorption ratio, and the ^{7}Be II/Mg II, ^{7}Be II/He II$_{1640}$, and ^{7}Be II/Hβ emission ratios, is N(Be)/N(H) $\approx$2.5 $\times$ 10^{-5} (by number), i.e. $\approx$1.7 $\times$ 10^{-4} by mass. This corresponds to an overproduction of ^{7}Be by about 1 dex in comparison with the theoretical models of massive CO and ONe novae. Since ^{7}Be all converts into ^{7}Li, the ^{7}Be/H abundance implies a ^{7}Li/H overabundance of about 4 dex over the ^{7}Li/H meteoritic value and indicates a total ejected mass of ^{7}Li of $\approx$9.5 $\times$ 10^{-10} M$_{\odot}$. These data are in line with previous observations and indicate that large amounts of ^{7}Li can be synthesized in a variety of novae, including very fast ONe novae.

Key words: stars: abundances – stars: individual: V838 Her – novae, cataclysmic variables – galaxies: abundances – galaxies: evolution – ultraviolet: general.

1 INTRODUCTION

Recent studies of the spectra of four novae in outburst attributed the presence of narrow and wide absorption features observed shortward of λ3130 to the resonance doublet of ^{7}Be II (Tajitsu et al. 2015, 2016; Molaro et al. 2016; Izzo et al. 2018). These findings prompted us to inspect the *International Ultraviolet Explorer* (*IUE*) archives for the presence of a similar strong absorption feature close to λ3130 in the post-outburst spectra of novae observed with the *IUE* (Boggess et al. 1978). For this purpose, we examined all low- and high-resolution *IUE* spectra of more than 30 novae in outburst secured in the *IUE* archive. The low-resolution mode of *IUE* ($R \approx$ 5.0 Å) is adequate for studying the presence of the wide absorption component, while the high resolution ($R \approx 0.2$ Å) is adequate to detect the possible presence of narrow absorption components. Here we discuss the notable case of V838 Her, while a detailed report on the entire data set will be presented in a forthcoming paper (Selvelli et al., in preparation).

2 V838 HER

V838 Her was discovered on 1991 March 24, and faded by 3 mag in the first 5 d ($t_3 = 5$ d; Vanlandingham et al. 1996), one of the fastest decline on record. The ultraviolet (UV) maximum occurred close to March 31, 7 d after optical maximum (Ingram et al. 1992; Starrfield et al. 1992; Leibowitz 1993). The nova outburst reached a large expansion velocity that was greater than 3000 km s^{-1}. Matheson, Filippenko & Ho (1993) and Vanlandingham et al. (1996) on the basis of the characteristics of the outburst and of the observed abundances suggested that the outburst occurred on a massive (1.35 M$_{\odot}$) ONe white dwarf (WD). A massive WD is also predicted by Kato, Hachisu & Cassatella (2009) from modelling of the optical and UV outburst light curve. However, Szkody & Ingram (1994) pointed out the observational difficulties of deriving a good value for the mass of the primary and from Hα radial velocity solution they found only a lower limit of M_1 > 0.62 M$_{\odot}$. *ROSAT* Position-Sensitive Pro-

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Table 1. Journal of the *IUE* spectra of V838 Her utilized in this work.

Day	Image	Disp.	Apert.	Date	Exp time
1	LWP19986	Low	Small	1991-03-25	19.538
1	SWP41180	Low	Large	1991-03-25	299.697
1	SWP41181	Low	Large	1991-03-25	1199.588
3	LWP19992	Low	Large	1991-03-26	29.778
3	LWP19992	Low	Small	1991-03-26	119.480
3	LWP19993	High	Large	1991-03-27	1799.659
3	SWP41192	Low	Large	1991-03-27	1199.588
3	LWP19994	High	Large	1991-03-27	3299.615
4	SWP41205	Low	Large	1991-03-28	419.710
4	LWP20001	Low	Large	1991-03-28	39.608
4	LWP20001	Low	Small	1991-03-28	179.691
4	SWP41206	Low	Large	1991-03-28	209.585
4	LWP20002	Low	Large	1991-03-28	19.538
12	LWP20085	Low	Large	1991-04-05	89.579
12	LWP20085	Low	Small	1991-04-05	179.691
12	SWP41303	Low	Large	1991-04-05	359.499
12	SWP41303	Low	Small	1991-04-05	599.524
15	LWP20103	Low	Large	1991-04-08	419.717
15	SWP41318	Low	Large	1991-04-08	359.499
15	SWP41318	Low	Small	1991-04-08	539.723
22	LWP20151	Low	Large	1991-04-15	779.755
22	SWP41391	Low	Large	1991-04-15	719.537
29	LWP20209	Low	Large	1991-04-22	1199.595
29	SWP41455	Low	Large	1991-04-22	1199.588

portional Counter (PSPC) observations in the 0.6–1.3 keV range detected V838 Her on 1991 March 30 (day 6), making it the first nova to be observed in X-ray within 5 d of an outburst (Trümper 1990). The X-ray emission was interpreted as shock heating by the interaction of the nova ejecta with pre-existing material, although the origin of this material was not clear (Lloyd et al. 1992; O'Brien, Bode & Kahn 1992). *IUE* studies mostly dealt with detailed abundances analysis from spectra taken during the nebular phase, about 1 month after the outburst and later: a notable spectroscopic feature was the significant underabundance of oxygen and the overabundance of neon (Vanlandingham et al. 1996; Schwarz et al. 2007).

3 *IUE* SPECTRA AND DATA REDUCTION

The *IUE* data bank contains 43 low-resolution and four high-resolution spectra of V838 Her, obtained with the Short-Wavelength Prime (SWP) and the Long-Wavelength Prime (LWP) cameras.

Table 1 provides the log of the subset of *IUE* spectra used in this study (we disregarded the spectra secured in the transition stage, between day 5 and 10, and those of the late stages). They were retrieved from the *IUE* Newly Extracted Spectra (INES) final archive.[1] The more relevant modifications in the INES system, in comparison with the New Spectral Image Processing System (NEWSIPS) format of the *IUE* final archive, are (1) the adoption of a new noise model; (2) a more accurate representation of the spatial profile of the spectrum; and (3) a more reliable determination of the background. For a detailed description of the *IUE*-INES system see Rodríguez-Pascual et al. (1999) and González-Riestra et al. (2001).

Some *IUE* SWP and LWP low-resolution spectra were obtained using both the large and the small aperture in the same image. We carefully checked all spectra for absence of saturation effects in the continuum or in the emission lines, a phenomenon that may occur longward of 1800 Å in the SWP camera, or close to 2800 Å in the LWP camera, where the sensitivity is higher. In some cases the best exposure was associated to the small aperture that suffers of throughput loss. To compare spectra taken with different apertures, the continuum of small aperture spectra was scaled to match the continuum level of the large aperture spectrum. This is justified because the time separation between the two spectra is of the order of a few tens of minutes. After these preliminary operations, good spectra taken in the same date were averaged to improve their signal-to-noise (S/N) ratio and SWP and LWP spectra were merged.

[1] http://sdc.cab.inta-csic.es/ines/

4 THE ^{7}BE II 3132 Å ABSORPTION FEATURE IN EARLY SPECTRA

The spectral distribution in the spectra taken in March exhibits an increase of flux towards longer wavelengths. This is due to the strong absorption caused by a crowding of lines of singly ionized metals. There are also several 'pseudo-emission' features close to λλ2640, 2885, 2980, which in most cases correspond to regions devoid of strong absorption lines. The spectral appearance of V838 Her is far more smoothed than in other novae owing to the high expansion velocity, ≥3000 km s^{-1}. As a consequence, even the high-resolution spectra are of little help in the direct identification of blended components.

In previous studies, little attention was paid to the early phases. Incidentally, we note here that, besides the resonance doublet of Mg II λ2796.35 and λ2803.53, hereafter Mg II λ2800, which is in emission even in the earliest spectra, some apparent emission lines close to λλ1240, 1405, 1483, 1550, 1750, 1815, and 1900, usually interpreted as 'windows' in the iron curtain, will actually correspond to common emission lines in later spectra. Remarkable features are the great flux excess close to λ1910 Å, a feature that becomes even more prominent after correction for the reddening, and the great strength of the steady absorption close to λ1850 Å, identified as the displaced Al III λ1860 resonance doublet.

Early spectra in both low- and high-resolution mode reveal the outstanding presence of a wide, strong absorption feature shortward of λ3130 Å (hereafter called λ3130 line); see Figs. 1 and 2.

We carefully looked for an identification of this absorption feature.

Considering the fact that the relevant spectra correspond to the 'iron curtain' stage of the nova outburst, the most probable candidates are the lines of singly ionized and, in some cases, neutral elements of the iron group, i.e. Fe II, Cr II, Ti II, and V II; see Table 3. However, the interpretation of the λ3130 absorption feature as a blend of absorption lines of only these species is questionable for the following considerations.

(i) The absorption strength of the λ3130 line is comparable to that of the Mg II λ2800 doublet and is stronger than any other absorption feature. A careful examination of the possible contributors close to λ3130, based on Moore (1959, 1962) tables and on the lists of atomic lines on the websites of NIST,[2] UK,[3] and Kurucz's,[4] confirmed that the sole candidates are the lines of singly ionized metals of Fe II, Cr II, Ti II, and possibly V II; see Table 3. However, lines of these ions arising from the same (or lower) term and with similar or higher oscillator strengths do not produce noticeable features in

[2] http://physics.nist.gov/cgi-bin/AtData/lines-form
[3] http://www.pa.uky.edu/peter/newpage/
[4] https://www.cfa.harvard.edu/amp/ampdata/kurucz23/sekur.html

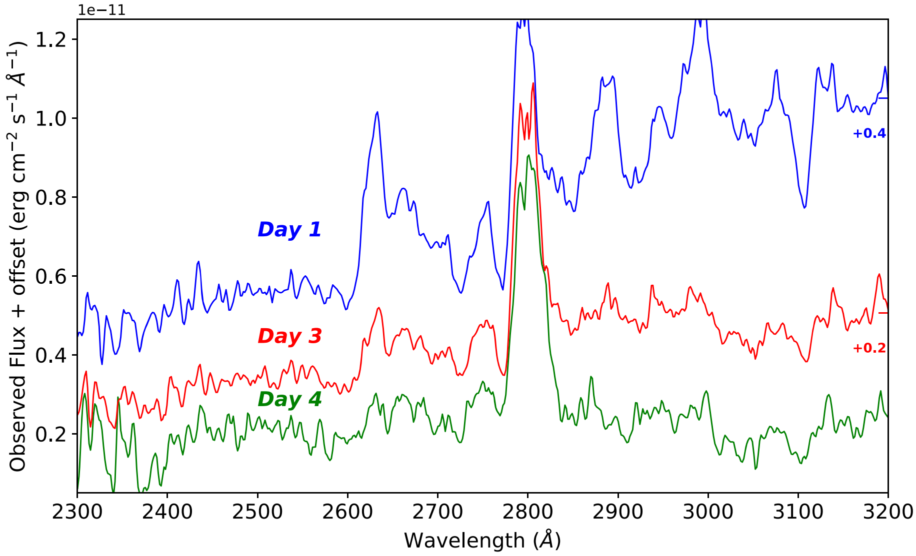

Figure 1. The low-resolution spectra of V838 Her in the early absorption stage that exhibit a deep absorption feature close to λ3120. The only definite emission line is Mg II λ2800; the other 'pseudo-emissions' are, probably, windows of the continuum.

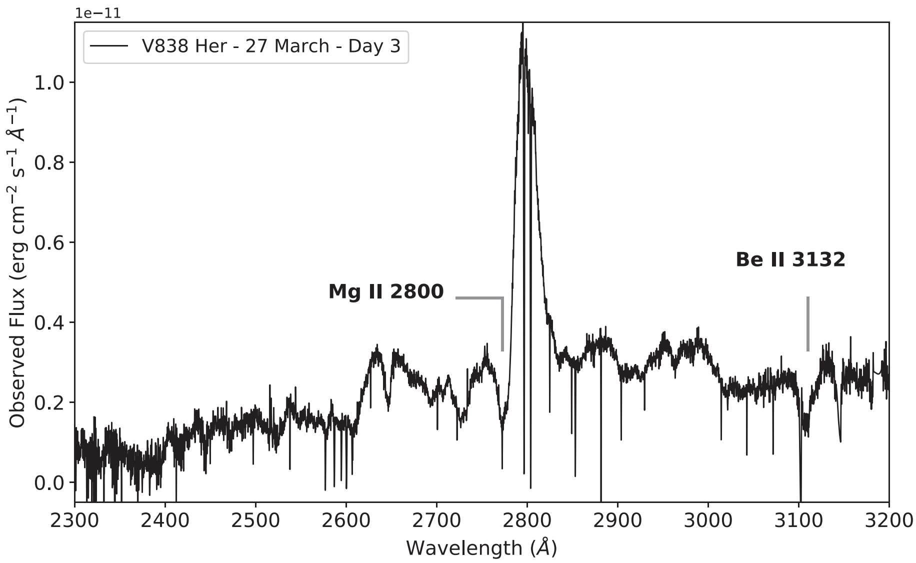

Figure 2. The high-resolution spectrum of day 3, which exhibits wide λ3132 and λ2800 absorption features and sharp Mg II interstellar lines, not resolved in Fig. 1. The other wide absorption features are blends of hundreds of strong Fe II and Cr II lines, broadened by the high expansion velocity. The plotted spectrum is the average of the two spectra LWP19993 and LWP19994 taken in sequence.

other spectral regions of the nova. We just mention the case of the many strong lines of Cr II arising from $\chi = 2.5$ eV. They may contribute to the observed λ3130 feature with about five strong lines, but a similar or stronger contribution is expected close to λλ2840–2860 taking into account the shortward displacement, where many strong Cr II lines with similar lower potential level are present, but only a weak absorption feature is detectable. The same reasoning is valid for the lines of Fe II: they contribute to the λ3130 line with only a few lines of moderate intensity. A far stronger contribution is expected close to λ2645 and in particular close to λ2730 where many strong Fe II lines are present, but the observed absorptions in the nova spectra at these wavelengths are similar or weaker than that close to λ3130. Therefore, the main contribution to the 3130 feature in V838 Her does not originate from a blend of Cr II and Fe II lines.

(ii) In the early stages the spectra of novae are those of an optically thick, expanding, cooling shell, and resemble those of early type stars, with blueshifted absorption lines (Schwarz et al. 2001; Warner 2008). A visual inspection of the *IUE* low-resolution spectra of A-shell stars has confirmed this and shown a general similarity in their overall line features and spectral distribution with the spectra of novae during the early 'iron curtain' stage. Besides the strong absorption features close to λλ2350, 2580, 2660, 2750, and 2870 that are all shortward displaced in novae, they generally exhibit also the same pseudo-emission features close to λλ2640, 2900, and 3000, usually observed also in novae at shorter wavelengths, and commonly interpreted as consequence of the limited number of absorption lines in these regions; see also Fig. 3. These spectroscopic similarities indicate similar ionization and excitation conditions. In novae, however, the strong line broadening due to expansion prevents a direct identification of the component absorption lines except by spectral modelling. Instead, the limited line broadening of these A-shell stars and the adequate resolution of the high-resolution *IUE* spectra allow a detailed identification of the relevant absorption features. Therefore, one can use the *IUE* high- and low-resolution spectra of A-shell stars as a template to interpret the nature of the absorption features observed in novae during the iron curtain phase. For this purpose, we studied the UV behaviour close to λ3130 and in nearby regions of a wide sample of 35 A-shell stars.

Our analysis indicates no evidence of strong absorption features close to λ3130, where the overall aspect is similar to that in adjacent spectral regions without any concentration of lines in this range. The absorption lines close to λ3130 are easily identified as transitions of Cr II, opt.(5), and Fe II, with minor contributions by Ti II and V II, mainly from the complete Kurucz's data base. For all 35 objects the comparison between the absorption strength in a 30 Å wide region centred close to λ3130 with the absorptions close to λ2750, where many strong Fe II lines are present, and λ2860, where many absorption lines of Cr II from the same lower level as the lines close to λ3130 are present, clearly shows that the absorption lines close to λ2750 and λ2860 are systematically more numerous and stronger than those close to λ3130, and produce deeper absorptions than in the 3130 region. Instead, the contrary is observed in the spectrum of V838 Her: the λ3130 absorption is far stronger than the other two. In A-shell stars we also observe a crowding of absorption lines close to λλ2620–2640, most of which are identified as Fe II and Cr II. However, the same objects exhibit only weak absorptions close to λ3130; see Fig. 3. On the contrary, in V838 Her the λ3130 absorption feature is stronger than that close to λ2665.

These findings are a clear proof of the presence of an additional strong absorption contribution close to λ3130, unless a peculiar and unidentified spectroscopic mechanism acted to reinforce the absorption lines of Cr II and Fe II close to λ3130 only in V838 Her, without reinforcing the other absorption lines of the same ions arising from the same or even lower terms.

(iii) The PHOENIX models (Hauschildt, Baron & Allard 1997) correctly reproduce the absorption features observed in the early *IUE* spectra of several novae but fail to reproduce the absorption feature close to λ3130, which is present in several spectra (see figs 5 and 6 in Hauschildt et al. 1994; figs 5, 7, and 10 in Schwarz et al. 1997; fig. 6 in Schwarz et al. 1998; and figs 7, 8, and 10 in Schwarz et al. 2001).

(iv) In the high-resolution spectra taken in the early phase, despite of the uncertainty associated with the correction of the echelle orders close to λ3130, there is a definite similarity between the profiles of the absorption features shortward of Mg II λ2800 and λ3130. If we refer to the nominal wavelengths of Mg II λ2800 and ^{7}Be II λ3132, the lines exhibit a similar velocity field structure and similar velocity displacement close to $-3000\,\mathrm{km\,s^{-1}}$; see Fig. 4. We consider the similarity in the profiles as another clear indication of the same spectroscopic nature of the two features, i.e. a resonance transition. Needless to say, there are no resonance lines close to the λ3130 region except the ^{7}Be II doublet λ3132.

In conclusion, atomic data and observations indicate that the strong and wide absorption feature close to λ3130 in V838 Her can be only partially explained as a blend of common iron curtain absorption lines. This agrees with the studies of recent novae by Tajitsu et al. (2015, 2016) and Molaro et al. (2016), who found only a minor contribution of singly ionized metal transitions to this feature.

A visual comparison between the absorptions close to λλ2660, 2750, 2860, and 3130 in A-shell stars and in V838 Her indicates that, on average, only a fraction of the λ3130 absorption of V838 Her is produced by lines of the Fe-peak elements.

Therefore, we confidently identify the 3130 feature as due mainly to the Be II resonance doublet and assume that it is ^{7}Be II λ (vac.) 3131.49 and λ (vac.) 3132.13 (hereafter ^{7}Be II λ3132) on the basis of this detection, from narrow components, in other novae.

5 THE ^{7}BE 3132 Å EMISSION LINE IN LATE SPECTRA

An emission feature centred close to λ3130 is observed in the low-resolution spectra taken in 1991 April; see Fig. 5.

This emission feature is quite commonly observed in planetary nebulae, symbiotic stars, novae, and other emission-line sources and is usually identified as O III λ3133.70, the strongest line produced in the Bowen fluorescence mechanism (BFM). For a general description of the BFM see Osterbrock & Ferland (2006) and Dopita & Sutherland (2003), while for a detailed analysis of the BFM in the symbiotic nova RR Tel see Selvelli, Danziger & Bonifacio (2007).

However, in the case of V838 Her the identification of the λ3130 emission feature as the O III λ3133.70 fluorescent line is improbable for these reasons.

(i) All UV and optical studies of V838 Her noted the absence or extreme weakness of the O III lines (Matheson et al. 1993; Starrfield et al. 1993; Vanlandingham et al. 1996; Schwarz et al. 2007). Downes, Duerbeck & Delahodde (2001), from a study of 96 novae, pointed out that V838 Her was an outlier in the sample because the [O III] λ5007 line was about 100 times fainter than all other novae. This can also be seen from fig. 4 of Williams, Phillips & Hamuy (1994) and figs 1 and 2 of Iijima & Cassatella (2010). The inspection of the *IUE* SWP spectra of V838 Her taken in April confirms beyond any doubt the absence of the common O III] λ1660–1666 emission lines, while other common emission lines, such as C IV λ1550, N III] λ1750, and C III] λ1906, in a range of ionization that encompasses that of O III, are clearly present (see Fig. 6).

This surprising peculiarity of V838 Her was pointed out recently.[5] We considered the possibility that the absence of the O III] and [O III] emission lines could simply be caused by a higher-than-critical electron density in the nebula, a situation in which the optical forbidden and the UV intercombination emission lines of O III are suppressed by collisional deexcitation. This is unlikely, because the UV O III] λ1666 line has a critical electron density n_e^{crit} of the order of 4.6×10^{10}electrons per cubic centimeter, a value that is higher than that implied by the presence of the intercombination lines of N III λ1750 (2×10^{10} cm^{-3}), and C III λ1908 (3.2×10^9 cm^{-3}), which are prominent in April spectra. Therefore, the faintness of the O III lines is a consequence of the underabundance of oxygen, in particular when compared to the abundance of carbon and nitrogen (see Fig. 6)

(ii) The BFM efficiency ε is defined as the fraction of the He II Lyα photons that are converted to O III photons, and can be estimated from the intensity ratio of a Bowen line (generally the λ3133.7 line)

[5] stsci.edu/∼ofox/posters2017/posters/starrfield/poster.pdf

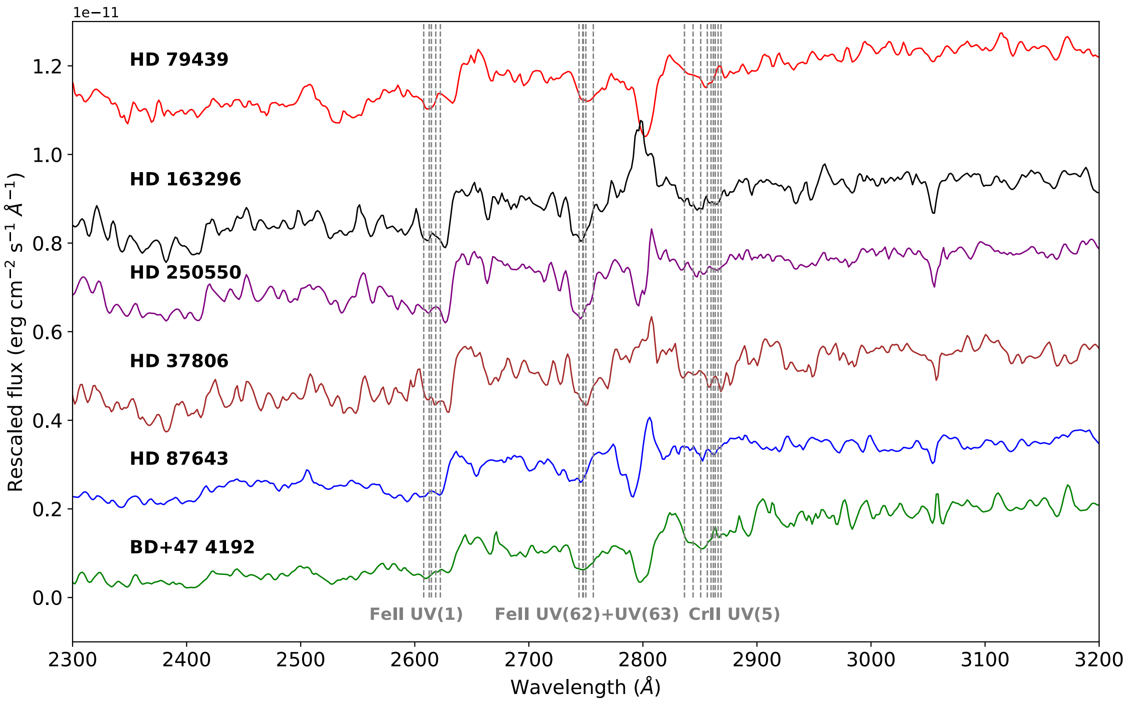

Figure 3. *IUE* low-resolution spectra of six A-shell stars in the near-UV. The λ3130 absorption feature is weak or absent, while other absorption features, e.g. λ2750 and λ2850, are stronger compared to those in V838 Her.

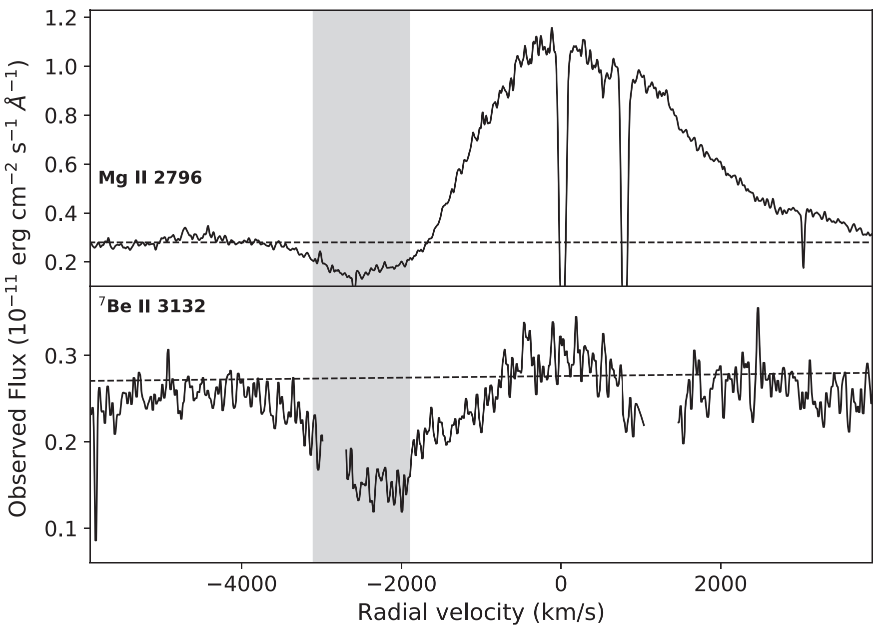

Figure 4. The P Cygni absorptions of the Mg II λ2800 and ^{7}Be II λ3132 lines in the *IUE* high-resolution spectrum of day 3. Note the similar velocity structure of the two resonant transitions. The gap close to −3000 km s^{-1} in the spectrum of ^{7}Be II corresponds to the absence of overlap between two adjacent echelle orders.

to that of a He II recombination line, e.g. λ1640. In this case $\varepsilon = 2.25 \times I_{3133.7}/I_{1640}$.
The data of Table 4, using the NUMPY (Van Der Walt, Colbert & Varoquaux 2011), and the ASTROPY (Astropy Collaboration et al. 2013) packages, and assuming that the λ3132 emission were due to O III λ3133.7, would give a weighted average intensity ratio of O III λ3133.7 to He II λ1640 = 0.17 ± 0.03. This would give an average conversion efficiency of $\varepsilon = 0.38 \pm 0.10$. This value is close to that found in planetary nebulae (see Weymann & Williams 1969; Likkel & Aller 1986; Liu & Danziger 1993; Dopita & Sutherland 2003). However, the Bowen fluorescence process requires low escape probability, i.e. high optical depths τ, in both the He II and the O III λ304 resonance lines, and the efficiency is related to the optical depths of these resonance lines. This depends on the number

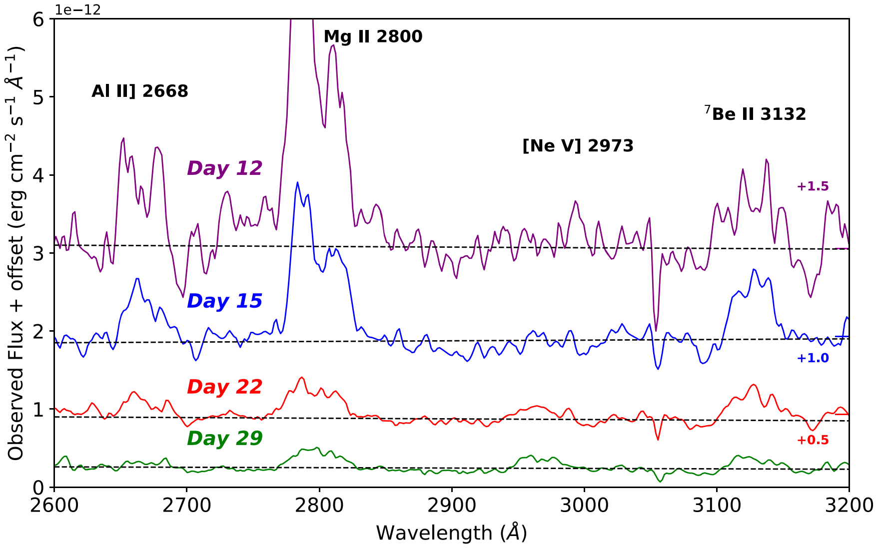

Figure 5. The Mg II λ2800 and ^{7}Be II λ3132 emission lines in the low-resolution spectra of 1991 April.

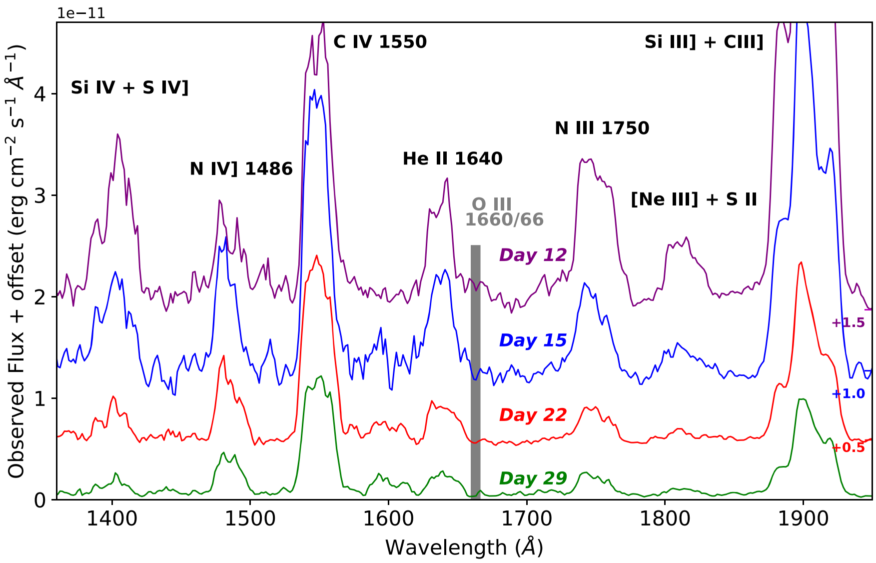

Figure 6. The emission lines of the far-UV low-resolution spectra in 1991 April. The absence of the commonly observed O III] λ1660–1666 emission feature is remarkable.

of absorbers, i.e. nebular mass and elemental abundances and on the expanding velocity $v_{\rm exp}$. Planetary nebulae (PNe) have mass ejecta close to 0.1–0.2 M$_\odot$ and low expansion velocities of approximately 20 km s^{-1}, and so high τ. On the contrary, Nova Her 91 has $v_{\rm exp} \approx$ 3000–4000 km s^{-1} and a shell mass of $\approx 10^{-5}$ M$_\odot$ (Vanlandingham et al. 1996; Schwarz et al. 2007).

A full treatment of the BFM was developed only for quasi-static-nebulae where line broadening is mostly by thermal velocities and detailed non stationary models do not exist (Kallman & McCray 1980; Dopita & Sutherland 2003). This would require a detailed study of the absorption and scattering of the relevant resonance photons in an expanding atmosphere, a quite complex theoretical task that is usually faced using the Sobolev approximation. This is beyond the scope of this paper. We just note that both Weymann & Williams (1969) and Kallman & McCray (1980) pointed out that velocity gradients in the nebula may decrease the optical depth in the line centres and increase line escape probabilities, substantially suppressing the efficiency of the BFM. Macroscopic velocity fields and velocity gradients increase the escape of photons, substantially suppressing the efficiency of the BFM if turbulent or flow velocities become comparable to thermal velocities, or higher (see Kallman & McCray 1980; Peraiah 2001; Dopita & Sutherland 2003).

From the observational side, Likkel & Aller (1986) noted that the optical depth of the Bowen O III transitions can be reduced by differential velocities such as expansion velocity, and pointed out that PNe with low efficiency have higher expansion velocities. The same conclusion, from a large sample of PNe, was reached by Liu & Danziger (1993) who found that in PNe the efficiency drops abruptly when the expansion exceeds some 30 km s^{-1}. Stickland et al. (1981), in a study of Nova Cyg 1978, noted that for a nova the transfer problem may be complicated due to possible large velocity gradients, which will tend to reduce the efficiency.

In RR Tel, Selvelli et al. (2007) found $\varepsilon \approx 0.30$ but here the lines are sharp and the large number of scatterings in the resonance lines of He II and O III favour the conversion of He II λ303.78 to O III λ303.80 and then to O III λ3133.7.

In this respect, it is worth noting that long ago Swings & Struve (1942) attributed the absence of BFM in the envelopes of WR stars, where O III lines were commonly observed, to their high expansion velocity. In their words, 'the O^{++} atoms located at a specific place in the WR shell are able to absorb the resonance radiation of only a small fraction of ejected He^{+} ions, since these must have a definite radial velocity with respect to the O^{++} atoms considered'. Swings & Struve (1942) concluded that in the case of spherical symmetry and of large constant expansion velocity BFM should be practically absent.

We argue that the reported presence of the BFM in some novae, if the identification of the 3130 emission feature as O III is taken for granted, may be explained by the large overabundance of oxygen in the ejecta of most novae, by a factor of up to 100–1000 compared to solar. This increases the optical depth in the O III λ304 resonance lines and compensates the negative effects of the expansion. The correlation between high abundances and BFM efficiency was noted by Netzer, Elitzur & Ferland (1985) in a study of BFM in active galactic nuclei (AGNs), and explained by the higher optical depth in the O III resonance lines. In Nova Cyg 1978 Stickland et al. (1981) found efficiency close to 0.80 but the ejecta were overabundant in oxygen by a factor of 25 and the expansion velocity was lower ($v_{\rm exp}$ $\sim 1000\,{\rm km\,s^{-1}}$) than in V838 Her.

Based on the two above-mentioned considerations, the absence of O III alone being sufficient, we confidently assume that ^{7}Be II λ3132 is the only plausible identification for the emission close to λ3130. Therefore, we conclude that both the shortward-displaced λ3130 absorption line, observed in the early stages, and the emission line centred close to λ3130, observed in the later stage, are identified as the resonance transition of ^{7}Be II.

We thank the referee for pointing out that the absence of other Bowen lines, i.e. λ2836 and λ3047, may also be evidence for the lack of BFM. These lines, although weaker by a factor of about 7 compared to λ3133.7 (see Kastner & Bhatia 1996; Selvelli et al. 2007), are expected to give a detectable emission if the feature close to λ3132 were the Bowen O III λ3133.7 line.

6 ^{7}BE ABUNDANCE ESTIMATE

We estimate the abundance of ^{7}Be both by comparing the equivalent widths (EWs) of the ^{7}Be II λ3132 with Mg II λ2800 absorption lines in the early spectra of March, and then, in the spectra of April, by comparing the emission intensity of ^{7}Be II λ3132 with those of Mg II λ2800, Hβ λ4861, and He II λ1640.

6.1 The absorption stage

Beryllium and magnesium have similar ionization potentials and a rough estimate of the their relative abundances can be derived from the ratio of the EWs of the ^{7}Be II λ3132 (W(3132)) and Mg II λ2800 (W(2800)) absorption doublets. From the data of Table 2, using the NUMPY (Van Der Walt et al. 2011), MATPLOTLIB (Hunter 2007), and the ASTROPY (Astropy Collaboration et al. 2013) packages, we derive a $(\sigma)^{-1}$ weighted average EW ratio of 1.80 ± 0.68, and a $(\sigma)^{-2}$ weighted average EW ratio of 1.28 ± 0.36 that we round to 1.5 ± 0.5.

It must be noted that the observed absorption EW of Mg II could be partially reduced by the presence of the emission component.

Table 2. The absorption equivalent widths (EWs) of ^{7}Be II 3132 and Mg II 2800 and their ratio in the early outburst stage of 1991 March.

Date	Resol.	W(Å)-3132	W(Å)-2800	3132/2800
Day 1	Low	11.2 ± 2.0	14.6 ± 0.8	0.76 ± 0.14
Day 3	High	10.5 ± 0.5	7.0 ± 0.3	1.50 ± 0.10
Day 3	Low	11.0 ± 3.0	9.6 ± 0.7	1.15 ± 0.32
Day 4	Low	11.2 ± 2.0	4.6 ± 0.8	2.43 ± 0.61

Table 3. A list of possible contributors by single ionized ions to the λ3130 absorption feature.

Wavelength (Å)	Ion	A_{ij} (s^{-1})	Level energy (eV)
3111.597	Ti II	2.667e+07	1.231332
3112.953	Ti II	2.327e+07	1.224145
3115.200	Fe II	6.384e+06	3.888695
3117.483	Fe II	6.990e+06	3.891610
3118.580	Ti II	5.937e+07	1.242992
3119.550	Cr II	1.713e+08	2.421358
3121.264	Cr II	1.504e+08	2.434119
3125.879	Cr II	8.186e+07	2.454790
3129.599	Cr II	8.149e+07	2.434119
3132.961	Cr II	8.151e+07	2.482828
3133.958	Fe II	1.599e+06	3.888695

Moreover, as explained by the considerations of Section 4 and Table 3, a minor but not negligible fraction of the measured EWs of the λ3130 line, which we estimate of the order of 10–20 per cent, is also contributed by lines of singly ionized elements, e.g. Cr II, Ti II, and Fe II. Therefore, the measured ratio of the EWs of ^{7}Be II λ3132 over Mg II λ2800 must be accordingly reduced by a factor that, following McLaughlin (1941) precept of 'erring on the side of conservatism', we assumed to have 2.0 as upper limit. Therefore, we adopt an average corrected ratio $W(3132)/W(2800) \sim 0.75 \pm 0.25$.

In the case of optically thin conditions, the EWs can provide a direct estimate of the number of absorbers (N_i) through the common relation:

$$W \propto N_i \times f_{ij} \times \lambda^2. \qquad (1)$$

Therefore, the relative population of the ground terms of the two ions can be easily derived using the relevant values of wavelength and oscillator strength (f_{ij}).

Since $f_{ij}(3132)/f_{ij}(2800) \sim 0.5$ and $W(3132)/W(2800) = 0.75 \pm 0.25$, it follows that

$$N_i(3132)/N_i(2800) = 1.20 \pm 0.40.$$

If the two ions are mostly in their ground term, the above derived ratio provides a reliable estimate of the ratio of ionic abundances. In addition, since the second ionization potentials of the two ions have similar values (i.e. 18.21 and 15.04 eV, respectively), similar ionization fractions are expected. Thus, the above derived ratio also provides an estimate of the total ^{7}Be/Mg abundance. The magnesium abundance in V838 Her is almost solar (Schwarz et al. 2007), 3.8×10^{-5} by number (Grevesse & Sauval 1998), and so the ^{7}Be abundance in V838 Her relative to hydrogen, by number, is given by

$$N(^7{\rm Be})/N({\rm H}) = 3.8 \times 10^{-5} \times 1.20(\pm 0.40) \sim 4.6 \pm 1.5 \times 10^{-5}.$$

A criticism of this approach could arise from the fact that the above relation between W and N_i is valid for optically thin conditions, while optical depth effects could be expected in the two resonance lines. However, the high-resolution spectra do not exhibit indication of saturation effects in the two lines: the line central depth is about 0.5 of that of the continuum level and indicates that the EW falls in the linear part of the curve of growth. In general, saturation effects are significantly reduced by the presence of a strong outflow velocity and in V838 Her $v_{\rm out}$ is greater than 3000 km s^{-1}. Also, the similarity between two lines that have similar EWs and exhibit a similar velocity profiles indicates that the two features are produced under similar conditions. This should alleviate the above reported criticism .

Another source of error arises from the uncertainty in the determination of the continuum to which the EWs are measured. However, from Fig. 2 we see that the continuum is clearly determined in the high-resolution spectra and at wavelength close to λ3000 Å the iron curtain effects are lower. Also, model atmospheres indicate that close to λ3000 Å the local continuum is similar to that of the black body (see figs 12 and 13 in Hauschildt et al. 1997). In any case, since the uncertainties regarding ^{7}Be II λ3132 and Mg II λ2800 are comparable, they compensate each other in the final ratio.

6.2 The emission stage

In April spectra of the emission lines allow an estimate of the ^{7}Be abundance from the comparison of the relative emission intensity of the λ3132 line with those of the Mg II λ2800, Hβ λ4861, and He II λ1640 lines. To use ratios of emission line intensities at different wavelengths the spectra must be dereddened. Previous determination of the reddening $E(B-V)$ from the literature are in the range 0.50 ± 0.10 mag (Vanlandingham et al. 1996; Kato et al. 2009).

We redetermined this quantity using the method based on the removal of the wide λ2175 Å interstellar absorption bump. Using SWP and LWP spectra taken at the same epoch, and using the reddening curve of Cardelli, Clayton & Mathis (1989), we estimated a colour excess $E(B-V) = 0.45 \pm 0.05$ mag, in agreement with previous values. Infrared (IR) maps (Schlafly & Finkbeiner 2011) indicate an upper limit of $E(B-V) = 0.37$ mag for the total galactic absorption in the direction of V838 Her. Therefore, we assumed $E(B-V) = 0.40$ mag as a final value and corrected the observed intensities accordingly.

6.2.1 The ^{7}Be II/Mg II ratio

The emission lines of the resonance transitions of Mg II λ2800 and ^{7}Be II λ3132 can be described by a simple two level atom in which the collisional excitation rate is in equilibrium with the rate of radiative decay and collisional de-excitation:

$$N_1 N_e q_{12} = N_2 A_{21} + N_2 N_e q_{21}. \tag{2}$$

Here q_{12} and q_{21} (cm^3 s^{-1}) are the collisional excitation and de-excitation rate coefficients, A_{21} (s^{-1}) is the Einstein coefficient for spontaneous decay from level 2, and N_e (cm^{-3}) is the electron density.

For $N_2 N_e q_{21} \ll N_2 A_{21}$, i.e. for $N_e \ll N_e^{\rm crit} = A_{21}/q_{21}$ one can neglect the second term in equation (2) and assume that every collisional excitation is followed by a radiative decay. In this case the line emissivity is

$$I_{21} = N_1 N_e q_{12} h\nu_{12} = N_2 A_{21} h\nu_{12}\ ({\rm erg\,cm^{-3}\,s^{-1}}). \tag{3}$$

For the case of the resonance transitions of ^{7}Be II and Mg II this is justified by the fact that their critical electron density A_{21}/q_{21} is high, i.e. of approximately of 10^{14} electrons per cubic centimeter, while N_e in the nebula is of the order of 10^7–10^8 cm^{-3} (Vanlandingham et al. 1996; Schwarz et al. 2007). Since most atoms are in the ground term, assuming same emitting volumes, one can write

$$N(^7{\rm Be\,II})/N({\rm Mg\,II}) = I_{3132}/I_{2880}\,(3132/2800)\,(q_{12}^{2800}/q_{12}^{3132}). \tag{4}$$

The ratio requires the knowledge of the collisional rate coefficients for Be II and Mg II:

$$q_{12} = (8.63\times10^{-6}\,\overline{\Omega}_{12}\,{\rm e}^{-\Delta E/KT_e})/(g_{12}\,T_e^{1/2}), \tag{5}$$

where g_{12} is the statistical weight $(2J+1)$ of the lower level of the transition, T_e is the electron temperature, ${\rm e}^{-\Delta E/KT_e}$ is the Boltzmann factor, and $\overline{\Omega}_{12}$ is the thermally averaged (effective) collision strength, an atomic parameter whose value is not accurately determined and, generally, is in the range 0.1–10.

The collision strength of the Be II resonance transition is not commonly included in the astrophysical literature and is not clearly determined. In the following, we assume $\overline{\Omega}(3132) = 11 \pm 4$ as a weighted average of several estimates (see Appendix A). Substitution of this value in the previous relation, with $T_e = 10\,000$ K (0.861 eV) and $\Delta E = 3.96$ eV, provides $q_{12}(\lambda3132) = (4.36 \pm 1.7) \times 10^{-9}$.

For Mg II the uncertainty of the effective collision strength (at about 10 000 K) is lower: in the following (see Appendix A) we assume $\overline{\Omega}$ (2800) = 16 ± 2 that, after substitution in the previous relations with $T_e = 10\,000$ K (0.861 eV) and $\Delta E = 4.43$ eV, provides $q_{12}(\lambda2800) = (4.35 \pm 0.9) \times 10^{-9}$.

Incidentally, it is worth pointing out that the reported underabundance of oxygen in V838 Her compared to other novae, and the consequent weakness of the oxygen lines, the most important coolants in a nebula, could have as a consequence an electron temperature higher than the value $T_e = 10^4$ that is usually assumed.

For the April spectra using the data in column 4 of Table 3 and the above-mentioned NUMPY (Van Der Walt et al. 2011) PYTHON package, we derived a $(\sigma)^{-1}$ weighted average emission ratio $I(3132)/I(2800) \sim 0.80 \pm 0.26$ (or 0.67 ± 0.134 in the case of a $(\sigma)^{-2}$ weight). From these values and the previous relations we find that the relative $N(^7$Be II)/N(Mg II) number ratio is $\sim$0.90 ± 0.46, where the final error originates from the propagation of the error in the emission intensity ratio and in the effective collision strengths, $\overline{\Omega}_{12}$, for the Mg II 2800 and Be II 3132 transitions.

The two ions have similar ionization potential and we can safely assume that $N(^7{\rm Be})/N({\rm Mg}) \approx N(^7{\rm Be\,II})/N({\rm Mg\,II})$. Since the abundance of magnesium in V838 Her is close to solar, from the relative Mg abundance in the Sun (Grevesse & Sauval 1998), we find that the abundance of ^{7}Be in the ejecta, compared to hydrogen in the Sun (by number), is

$$N(^7{\rm Be})/N({\rm H}) = 3.4(\pm1.7)\times10^{-5}.$$

For the correction by the decay of ^{7}Be see Section 6.2.4.

6.2.2 The ^{7}Be II λ3132/Hβ ratio

To the best of our knowledge, there is no published information about the emission line intensity of Hβ in the spectra of V838 Her taken in April. There are, however, two indirect sources of information.

(i) Schwarz et al. (2007) reported a ratio He II λ1640 over Hβ, $I_{1640}/I_{4861} = 6.9$ for 1991 April 22, but did not provide the intensity of Hβ. Since an *IUE* SWP spectrum of the same date is available, using this ratio one could estimate the intensity of Hβ. However, Schwarz et al. (2007) found the ratio using a reddening correction

$E(B-V) = 0.60$ mag instead of $E(B-V) = 0.40$ we derived. In this latter case the correct ratio becomes about 3.3 and from our direct measurement of $I_{1640} = 51.0 \times 10^{-12}$ erg cm^{-2} s^{-1}, we estimate that $I_{4861} = 15.4 \times 10^{-12}$ erg cm^{-2} s^{-1}.

(ii) Williams et al. (1994) found $I_{4861}/I_{4686} \sim 0.5$ on April 25. Since the expected theoretical ratio I_{1640}/I_{4686} is $\sim$7.0 (Dopita & Sutherland 2003), we find that $I_{4861} \sim 3.6 \times 10^{-12}$ (erg cm^{-2} s^{-1}). This is a lower limit because for earlier epochs (i.e. April 22) one expects a higher I_{4861}/I_{4686} ratio, and so a value of I_{4861} close to 5.0×10^{-12} erg cm^{-2} s^{-1} appears appropriate.

Based on the two above-mentioned estimates, we assume $I_{4861} \sim (10.0 \pm 5.0) \times 10^{-12}$ erg cm^{-2} s^{-1}. This provides a ratio $I_{3132}/I_{4861} = 0.8 \pm 0.56$ for April 22.

The ratio of the reddening corrected emission intensities can be used to estimate the number of atoms and the relative abundances adapting to our case the relation (Mihalszki & Ferland 1983; Osterbrock & Ferland 2006)

$$N(^7\mathrm{Be\,II})/N(\mathrm{H}^+) = 3132/4861 \times \alpha_{\mathrm{eff}}^{4861}/q_{12}^{3132} \times I_{3132}/I_{4861}. \quad (6)$$

For $T_e \approx 10\,000$ and $\log N_e \approx 6$–7, the effective recombination coefficient is $\alpha_{\mathrm{eff}}^{4861} \approx 3.05 \times 10^{-14}$ cm^3 s^{-1}, with small variations about these values of T_e and N_e (Osterbrock & Ferland 2006). Since $q_{12}^{3132} = (4.36 \pm 1.74) \times 10^{-9}$ we find

$$N(^7\mathrm{Be\,II})/N(\mathrm{H}^+) = 3.6 \sim (\pm 2.4) \times 10^{-6}.$$

The above reported value is probably a lower limit for the ^{7}Be abundance because at this epoch some ^{7}Be is also in the ^{7}Be^{++} ionization stage (^{7}Be III spectrum), due to its relatively low second ionization potential (18.21 eV).

The final quite large error derives from the propagation of the individual uncertainties of the line intensities, especially Hβ, and from that of the effective collision strength $\overline{\Omega}_{12}$ for the ^{7}Be II λ3132 transition.

This apparent value for April 22 must be corrected for the decay of ^{7}Be, see Section 6.2.4.

6.2.3 The ^{7}Be II λ3132/He II λ1640 ratio

Another constrain to the ^{7}Be abundance can be found using the observed emission line ratio I_{3132}/I_{1640} in the spectra of April. The above relation, 'mutatis mutandis', becomes

$$N(^7\mathrm{Be\,II})/N(\mathrm{He\,II}) = I_{3132}/I_{1640} \times 3132/1640 \times \alpha_{\mathrm{eff}}^{1640}/q_{12}^{3132} \quad (7)$$

that, after substitution of the numerical values (Osterbrock & Ferland 2006), i.e.

$$\alpha_{\mathrm{eff}}^{1640} = 8.1 \times 10^{-13}, \quad q_{12}^{3132} = 4.36(\pm 1.7) \times 10^{-9},$$

and of the average I_{3132}/I_{1640} ratio $= 0.20 \pm 0.05$, gives

$$N(^7\mathrm{Be\,II})/N(\mathrm{He\,II}) = 7.1(\pm 3.3) \times 10^{-5}.$$

The lack of knowledge about the ionization fractions is quite a problem because helium is also He I and ^{7}Be could be twice ionized; it is worth noting that neutral helium has a higher ionization potential than singly ionized ^{7}Be and He II is strong. Therefore, on the one hand the ^{7}Be/He abundance could be higher if most ^{7}Be were ^{7}Be III, on the other hand ^{7}Be/He could be lower if most of helium where He I, with a possible compensation between the two effects.

It appears, however, that helium is mostly He II as results from the ratio He II(1640)/He I(5876) = 35 in April 22 (Schwarz et al. 2007). In this case (helium mostly He II), from the above reported relation, and noting that Schwarz et al. (2007) found that in V838 Her helium is overabundant by a factor close to 1.4 compared to solar (i.e. He/H $\sim$ 0.14), we derive a lower limit:

$$N(^7\mathrm{Be})/N(\mathrm{H}) = 1.0(\pm 0.45) \times 10^{-5}.$$

See Section 6.2.4 for the correction for the decay of ^{7}Be.

Table 4. The emission line intensities (10^{-11} erg cm^{-2} s^{-1} Å^{-1}) of He II λ1640, Mg II λ2800, and ^{7}Be II λ3132 and their ratios in 1991 April. All measurements are from low-resolution spectra. The observed intensities were corrected for $E(B-V) = 0.40$.

Day	*I*-1640	*I*-2800	*I*-3132	3132/2800	3132/1640
12	22.2 ± 1.0	9.7 ± 0.2	5.5 ± 1.1	0.57 ± 0.11	0.25 ± 0.05
15	21.2 ± 1.1	4.3 ± 0.2	2.8 ± 0.2	0.65 ± 0.06	0.13 ± 0.01
22	8.7 ± 0.5	1.3 ± 0.1	1.5 ± 0.2	1.15 ± 0.18	0.17 ± 0.03
29	5.1 ± 0.3	1.25 ± 0.1	0.8 ± 0.2	0.64 ± 0.17	0.16 ± 0.04

Table 5. The average ^{7}Be/H (number) derived from ratios of absorption and emission lines. The values are corrected for the decay of ^{7}Be.

Stage	Method	^{7}Be/H
Abs.	^{7}Be II(3132)/Mg II(2800)	4.6 (±1.5) × 10^{-5}
Em.	^{7}Be II(3132)/Mg II(2800)	4.4 (±2.2) × 10^{-5}
Em.	^{7}Be II(3132)/He II(1640)	1.3 (±0.6) × 10^{-5}
Em.	^{7}Be II(3132)/HI(4861)	0.5 (±0.4) × 10^{-5}

6.2.4 The average ^{7}Be and ^{7}Li abundances

The observed abundance of ^{7}Be II must be corrected for the radioactive decay after its synthesis, assumed to take place entirely in the early outburst phases. The correction for the half-life of 53.22 d is almost negligible for the early absorption spectra taken a few days after the outburst. Instead, it is, on average, by a factor of $\approx$1.30 for the abundances found in April from the emission line ratio I_{3132}/I_{2800} of ^{7}Be II/Mg II, and I_{3132}/I_{1640} of ^{7}Be II/He II (from day 12 to day 29), and by a factor of 1.46 for the abundance from the ratio I_{3132}/I_{4861} of ^{7}Be II/H I for April 22. The final values are reported in Table 5.

These four values are quite consistent, in view of the various uncertainties that may have affected their calculations, and indicate a weighted average ^{7}Be/H ratio of approximately of $\approx 2.5 \times 10^{-5}$ (by number), i.e. of $\approx 1.7 \times 10^{-4}$ by mass (note that more weight was given to the results from the direct ^{7}Be II/Mg II ratio).

This corresponds to an overproduction of ^{7}Be by factors of about 8 and 40, respectively, in comparison with the theoretical models of (massive) CO and ONe novae of José & Hernanz (1998) and Hernanz & José (1998) that indicate an average mass ratio ^{7}Be/H close to 2×10^{-5} and 4×10^{-6}, respectively.

Since ^{7}Be all converts into ^{7}Li the corresponding ^{7}Li/H ratio ($\approx 2.5 \times 10^{-5}$, by number) indicates an overabundance by about 4 dex over the ^{7}Li meteoritic value (^{7}Li/H $= 1.86 \times 10^{-9}$; Asplund et al. 2009; Lodders, Palme & Gail 2009), that is an overproduction by about 1 dex over the models of José (2016) (cf. their fig. 4.12). These results fairly agree with the overabundance of 4.7 dex relative to the meteoritic abundance of Molaro et al. (2016) for V5668 Sgr 2.

If the ejecta mass is $\sim 1.0 \times 10^{-5}$ M$_\odot$ (Vanlandingham et al. 1996; Schwarz et al. 2007) and the ^{7}Li /H mass ratio is about 1.7×10^{-4}, assuming m(H)/m(tot) $\sim 5.6 \times 10^{-1}$ (Schwarz et al. 2007), then the total ejected mass of ^{7}Li is of about 9.5×10^{-10} M$_\odot$.

7 DISCUSSION

The possibility of the synthesis of ^{7}Be and of its transport during outburst to the outer nova layers in a process similar to the ^{7}Be transport mechanism in red giants (Cameron 1955; Cameron & Fowler 1971) represented a long debated and controversial issue in the studies of nova nucleosynthesis. See José & Hernanz (2007) and José (2016) for a comprehensive review and detailed considerations on this subject.

It is commonly accepted that ^{7}Be is produced by the α-capture reaction ^{3}He$(\alpha,\gamma)^7$Be of the pp2 chain. This is the only exception to the absence of α-captures in the pp chains (José & Hernanz 2007). If the unstable ^{7}Be with a half-life of 53.22 d, survives destruction via the proton capture reaction ^{7}Be$(p,\gamma)^8$Be that would complete the pp3 chain, the reaction of the pp2 chain is followed by an inner shell electron capture on ^{7}Be with production of ^{7}Li.

The hydrodynamic simulations with a full reaction network of Hernanz et al. (1996) and José & Hernanz (1998) confirmed the feasibility of the ^{7}Be transport mechanism in nova outburst. Hernanz & José (2000, 2004) and José (2002) also found that CO novae are favoured in comparison with ONe novae for ^{7}Be synthesis because their faster rise evolution to $T \approx 10^8$ K in the early outburst phases, driven by their larger amount of ^{12}C content, favours ^{7}Be survival: ^{7}Be destruction through the deadly p-capture reactions is prevented due to the efficient role played by the inverse photodisintegrations on ^{8}B$(\gamma$,p$)^7$Be (José & Hernanz 2007; Isern, Hernanz & José 2011; José 2016).

Needless to say, a critical aspect in the studies of nova OB is the treatment of hydrodynamic effects such as the convective transport induced by the large amount of energy released through the CNO cycle. Convection with its extension throughout the envelope plays a fundamental role not only in the transportation of the energy released in the ignition core, but also in the mixing of material at the core envelope interface (Truran 1998; Hernanz & José 2000; Starrfield, Iliadis & Hix 2016).

In the specific case of the ^{7}Be transport mechanism, the observation of ^{7}Be and ^{7}Li requires that ^{7}Be has to be transported by convection to low-temperature zones in a short time-scale. Therefore, the observed abundance of ^{7}Be (and ^{7}Li) in the ejecta is sensitive to the rate at which it is transported to the outer, cooler layers prior to its decay to ^{7}Li (see Starrfield, Iliadis & Hix in Bode & Evans 2012, and see also Isern et al. 2011). Regrettably, the efficiency of mixing by convection is a critical parameter (see e.g. Boffin et al. 1993). Hernanz et al. (1996) computed the production of ^{7}Be during nova outbursts by means of a hydrodynamic code and derived an average mass fraction of ^{7}Be in the shell of about 10^{-6}–10^{-5} M$_\odot$ (see table 4 in Hernanz & José 1998) and so about 1×10^{-10}–1.2×10^{-11} M$_\odot$ of ^{7}Be were ejected in a CO and a ONe nova, respectively.

Wanajo, Hashimoto & Nomoto (1999) also found that CO novae may produce about 10 times more ^{7}Be than ONe novae, with ^{7}Be abundances in mass fraction of up to 10^{-6} for $T_{\rm peak} \sim$ 3–4 times 10^8 K, but they found that for the same $T_{\rm peak}$ the models with lower WD mass produce more ^{7}Be than higher ones. It should be noted, however, that these models were criticized by Downen et al. (2013), as based on outdated thermonuclear reaction rates.

In principle, this complex theoretical scenario could be tested with observational data by comparing the ^{7}Be yields in CO and ONe novae, respectively. Regrettably, in the case of V838 Her the observational constrains, i.e. the positive detection of ^{7}Be II, the extremely fast light-curve character, the depletion of oxygen, and the strong enrichment of sulphur and aluminium (Schwarz et al. 2007), indicate a contradictory scenario for the nature of the WD and the nova character.

(i) The presence of a massive CO nova ($M_1 \leq 1.15$ M$_\odot$) is required by models (Hernanz & José 1998) as the most probable site for ^{7}Be synthesis, characterized by larger ^{7}Be production, by a factor close to 10, compared to ONe novae. Models also indicate that fast novae such as V838 Her require oxygen enhancement by strong mixing with the CO interface. In this respect, the depletion of oxygen in the ejecta of V838 Her is a disturbing piece of evidence.

(ii) The presence of a massive ONe WD in V838 Her is indicated by the following facts: (a) all spectroscopic studies pointed out the presence of exceptionally strong [Ne III] 3869–3968 and [Ne V] 3346–3428 emission lines in late phases, see in particular fig. 4 in Williams et al. (1994); (b) the extremely fast character of the light curve and the high expansion velocity require a massive WD of approx 1.35 M$_\odot$, i.e. a ONe WD (Matheson et al. 1993; Vanlandingham et al. 1996; Kato et al. 2009); (c) the observed overabundances of sulphur and aluminium by a factor of about 30 compared to solar require mixing with an underlying massive ONe (and not CO) WD, because CO WDs are devoid of these overabundant nuclei (José et al. 2004; Hernanz & José 2005).

As noted in Section 2, the WD mass, a fundamental parameter in all the above-mentioned considerations, is poorly determined from direct radial velocity data despite the orbital high inclination. Clearly a new direct estimate of the mass would be of paramount importance for a direct test of the validity of the theoretical expectations.

It is worth mentioning that the depletion of oxygen and the significant enrichment in heavier elements such as sulphur and aluminium was considered as an observational evidence that breakout from the CNO cycle may have occurred in a massive ONe WD (Schatz 2004; Schwarz et al. 2007; Glasner & Truran 2009). However, modelling of the outburst of V838 Her (Downen et al. 2013; Champagne, Iliadis & Longland 2014) indicated a massive (1.34–1.35 M$_\odot$) ONe WD, without compelling evidence for breakout ($T_{\rm peak}$ in the TNR close to 3×10^8 K).

It should be also noted that the hydrodynamic models of Politano et al. (1995) and José & Hernanz (1998) predict a sharp reduction of oxygen and significant increase of sulphur as the WD mass increases, although, as pointed out by Schwarz et al. (2007), in the case of V838 Her both models fail to produce the observed mass fraction of sulphur.

In conclusion, the presence of large amounts of ^{7}Be represents an additional peculiar aspect of the properties of V838 Her that was considered as a 'unique' object (Schwarz et al. 2007) even before the detection of ^{7}Be II.

Probably, this uniqueness is an indication that nova models are not yet fully predictive of the entire variety of possibilities that nature offers.

We note that ^{7}Be has been positively detected so far in slow novae only (see Molaro et al. 2016; Tajitsu et al. 2016). However, Izzo et al. (2018) detected ^{7}Be also in the fast ONe V407 Lup. Therefore, these last observations, summarized in Table 6, indicate that synthesis of ^{7}Be may take place both in slow and in very fast novae, and that ONe novae are also candidate sites.

8 CONCLUSIONS

(i) By a detailed analysis of archival *IUE* spectra of V838 Her we provided proofs that ^{7}Be was produced in the outburst of V838 Her.

Table 6. The ^{7}Be/H (number) for the three novae with narrow absorption components. The original values from Tajitsu et al. (2015, 2016) are corrected here for the decay of ^{7}Be. References are (1) Tajitsu et al. (2015), (2) Molaro et al. (2016), (3) Izzo et al. (2018), and (4) Tajitsu et al. (2016).

Nova	Type	Day	Comp	^{7}Be/H	Ref.
V339 Del	CO	47	−1103	1.9×10^{-5}	1
		47	−1268	3.2×10^{-5}	1
V5668 Sgr	CO	58	−1175	1.7×10^{-4}	2
		82	−1500	1.3×10^{-4}	2
V2944 Oph	CO	80	−645	1.6×10^{-5}	4
V407 Lup	ONe	8	−2030	6.2×10^{-5}	3

For the first time the resonance line of ^{7}Be II is also detected in emission.

(ii) From abundance analysis using both absorption and emission lines of ^{7}Be II we derive an average ^{7}Be/H ratio of approximately $\approx 2.5 \times 10^{-5}$ (by number) or of $\approx 1.7 \times 10^{-4}$ (by mass). This corresponds to an overproduction by a factor of about 8 and 40, respectively, if compared to models of massive CO and the ONe novae (Hernanz & José 1998; José & Hernanz 1998).

(iii) Since ^{7}Be all converts into ^{7}Li the corresponding ^{7}Li/H ratio ($\approx 2.5 \times 10^{-5}$, by number) corresponds to an overabundance by about 4 dex over the ^{7}Li meteoritic value and an overproduction by about 1 dex in comparison with the values in fig. 4.12 of José (2016).

(iv) If the mass of the ejected shell is $\sim 1.0 \times 10^{-5}$ $M_\odot$ (Vanlandingham et al. 1996; Schwarz et al. 2007), the total ejected mass of ^{7}Li is of about 9.5×10^{-10} $M_\odot$.

(v) Models favour higher synthesis of ^{7}Be in CO novae compared to ONe novae, although for ONe WD of 1.35 $M_\odot$ the overproduction factors are similar (José 2016). Our results and those of V5668 Sgr by Molaro et al. (2016) and V407 Lup by Izzo et al. (2018) indicate that indeed ONe novae produce less ^{7}Be than CO novae (although in larger amounts than models).

(vi) The present detection of ^{7}Be in V838 Her, the previous detections of ^{7}Be (or ^{7}Li) in V339 Del (Tajitsu et al. 2015), V2944 Oph (Tajitsu et al. 2016), V5668 Sgr (Molaro et al. 2016; Tajitsu et al. 2016), V1369 Cen (Izzo et al. 2015), and the detection of ^{7}Be in V1369 Cen (Izzo et al. 2015) and V407 Lup (Izzo et al. 2018) confirm that ^{7}Be can be synthesized in a variety of novae, including slow novae and very fast novae, and that ONe novae are also candidate places.

(vii) The presence of large amounts of ^{7}Be, with the depletion of oxygen and the overabundance of sulphur (possible indications of breakout in a massive ONe WD), adds another peculiar aspect to the properties of V838 Her and confirms its characteristics as a 'unique' object.

(viii) José & Hernanz (2007) concluded their comprehensive review on nucleosynthesis in CNe explosion by stating 'unambiguous detection of ^{7}Li has become a challenge: theoretical models suggest a huge overproduction of such isotope, particularly in CO novae, but detection faces the likely superposition of lines corresponding to different species'. In this respect, it is worth pointing out that the detection of the ^{7}Be II resonance lines in recently observed novae and in V838 Her, observed with *IUE*, has opened a new, promising and alternative way to confirm the effectiveness of the whole process of ^{7}Li nucleosynthesis in novae.

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APPENDIX A: THE COLLISION STRENGTH OF Be II λ 3132 AND Mg II λ 2800

The effective collision strength $\overline{\Omega}$ of the Be II λ3132 resonance transition is not commonly listed in astrophysical literature.

Osterbrock & Ferland (2006) and Dopita & Sutherland (2003) provide collision strengths for the 2s–2p (^{2}S–^{2}P$^{\rm o}$) transitions for ions of the Li I isoelectronic sequence (i.e. C IV, N V, and O VI) but not for Be II. Extrapolation to Be II of the tabulated values for the CNO ions indicates $\overline{\Omega} \approx$ 10–12. Other estimates can be found in literature both from various atomic models and from experimental cross-sections, resulting in a range of values for $\overline{\Omega}$ for Be II; an assessment of collision strengths for lithium-like ions was made by McWhirter (1994), using $\overline{\Omega}$ values based on the experimental cross-section by Taylor, Phaneuf & Dunn (1980) and Mitroy & Norcross (1988). Extrapolation of these values to $KT \sim 1$ eV indicates $\overline{\Omega} \sim 10$. The Los Alamos theoretical online tables,[6] for $KT \sim 4$ eV, indicate $\overline{\Omega} \approx$12, while the Universal Fit Formula of Cochrane and McWhirter (McWhirter 1994) indicates $\overline{\Omega} \sim 14$. In this study we assume $\overline{\Omega}(3132) = 11 \pm 4$ as a weighted average of these estimates.

It is worth noting, however, that while the comparison between laboratory measurements and theoretical work on electron impact coefficients agrees with theory for most ions of the Li isoelectronic sequence, there is a long standing discrepancy for Be II (Dere et al. 1997).

For Mg II the uncertainties regarding the effective collision strength are lower: Osterbrock & Ferland (2006) (table 3.3) give 16.9. Similar values are found in Mendoza (1981), Dopita & Sutherland (2003), and Sigut & Pradhan (1995). The Los Alamos theoretical estimates give $\overline{\Omega} \sim 20$, while Smith et al. (1993) give values of about 10–20 for the collision strength close to 4–5 eV. In this study we assume $\overline{\Omega}(2800) = 16 \pm 2$ as a weighted average of these values.

[6] http://aphysics2.lanl.gov/tempweb/lanl/

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