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

Selvelli, P., Molaro, P., Izzo, L.

$^{1}$ INAF-Osservatorio Astronomico di Trieste, Via G.B. Tiepolo 11, I-34143 Trieste, Italy

$^{2}$ Instituto de Astrofísica de Andalucía, Glorieta de la Astronomía s/n, 18008, Granada, Spain

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ABSTRACT

High and low resolution IUE spectra of V838 Her in the early outburst stages exhibit a strong absorption feature shortward of $\lambda$3130. We discuss the nature of this spectral feature and provide convincing evidence that it corresponds to the blue-shifted resonance doublet of singly-ionized $^{7}\text{Be}$ recently discovered in other novae. During the evolution of the outburst the appearance of an emission feature close to $\lambda$3130 Å is also identified as $^{7}\text{Be}^{\text{ii}}$ $\lambda$3132 because the usual identification as the O$^{\text{iii}}$ $\lambda$3133.7 Bowen fluorescence line is hardly compatible with both the known oxygen under-abundance in the nova ejecta and the low optical depths in the nebula due to the high outflow velocity. The average $^{7}\text{Be}$ abundance relative to hydrogen, estimated by four different methods, i.e. the $^{7}\text{Be}^{\text{ii}}$/Mg$^{\text{ii}}$ absorption ratio, and the $^{7}\text{Be}^{\text{ii}}$/Mg$^{\text{ii}}$, $^{7}\text{Be}^{\text{ii}}$/He$^{\text{ii}}$1640, and $^{7}\text{Be}^{\text{ii}}$/H$^{\beta}$ 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 $^{7}\text{Be}$ by about 1 dex in comparison with the theoretical models of massive CO and ONe novae. Since $^{7}\text{Be}$ all converts into $^{7}\text{Li}$ by about 1 dex, the $^{7}\text{Li}$/H abundance implies a $^{7}\text{Li}$/H overabundance of about 4 dex over the $^{7}\text{Li}$/H meteoritic value and indicates a total ejected mass of $^{7}\text{Li}$ of $\approx$ 9.5$\times$10$^{-10}$ $M_\odot$. These data are in line with previous observations and indicate that large amounts of $^{7}\text{Li}$ can be synthesized in a variety of novae, including very fast ONe novae.

Key words: stars: individual V838 Her; stars: novae – nucleosynthesis, abundances; Galaxy: evolution – abundances

1 INTRODUCTION

Recent studies of the spectra of four novae in outburst attributed the presence of narrow and wide absorption features observed shortward of $\lambda$3130 to the resonance doublet of $^{7}\text{Be}^{\text{ii}}$ (Tajitsu et al. 2015, 2016; Molaro et al. 2016; Izzo et al. 2018). These findings prompted us to inspect the IUE archives for the presence of a similar strong absorption feature close to $\lambda$3130 in the post outburst spectra of novae observed with the International Ultraviolet Explorer (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 dataset will be presented in a forthcoming paper (Selvelli et al., in preparation).

2 V838 HER

V838 Her was discovered on March 24, 1991, and faded by 3 magnitudes in the first five days ($t_3 = 5$ days, Vanlandingham et al. 1996), one of the fastest decline on record. The UV maximum occurred close to March 31, seven days 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$^{-1}$. Mathe son et al. (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 et al. (2009) from modelling of the optical and UV outburst lightcurve. However, Szkody & Ingram (1994) pointed out the observational difficulties of deriving a good value for the mass of the primary and from H$^\alpha$ radial velocity solution they found only a lower
limit of \( M_1 > 0.62 \text{ M}_\odot \). ROSAT PSPC (Position Sensitive Proportional Counter) 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 days 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 et al. 1992). IUE studies mostly dealt with detailed abundances analysis from spectra taken during the nebular phase, about one month after the outburst and later: a notable spectroscopic feature was the significant under-abundance of oxygen and the overabundance of neon (Vanlandingham et al. 1996; Schwarz et al. 2007).

### 3 IUE SPECTRA AND DATA REDUCTION

The IUE databank contains 43 low resolution and 4 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. 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; 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 sensitivity is higher. In some cases the best exposure was

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

| Date | Resol. | W(Å)-3132 | W(Å)-2800 | \( \text{W(Å)} / 2800 \) |
|------|--------|-----------|-----------|-----------------|
| Day 1 | Low    | 11.2 ± 2.0 | 14.6 ± 0.8 | 0.76 ± 0.14 |
| Day 3 | Hi     | 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 ± 0.64  |

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 \( \lambda \lambda 2640, 2885, 2980 \), 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, \( \gtrsim 3000 \text{ km s}^{-1} \). 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 \(^{Mg\,II} \) 22796.35 and \( \lambda 2803.53 \), hereinafter \(^{Mg\,II} \) \( \lambda \lambda 2800, 2800 \), which is in emission even in the earliest spectra, some apparent emission lines close to \( \lambda \lambda 1240, 1405, 1483, 1550, 1750, 1815, 1900 \), 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 \( \lambda 1910 \) Å, a feature that becomes even more prominent after correction for the reddening, and the great strength of the steady absorption close to \( \lambda 1850 \) Å, identified as the displaced \( \lambda \lambda 1860 \) resonance doublet.

Early spectra in both low and high resolution mode reveal the outstanding presence of a wide, strong absorption feature shortward of \( \lambda 3130 \) Å (hereinafter called \( \lambda 3130 \) line), see Fig. 1 and Fig. 2.

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1 http://sdc.cab.inta-csic.es/ines/
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\textsc{ii}, Cr\textsc{ii}, Ti\textsc{ii}, V\textsc{ii}, see Table 3. However, the interpretation of the \( \lambda 3130 \) absorption feature as a blend of absorption lines of only these species is questionable for the following considerations:

- The absorption strength of the \( \lambda 3130 \) line is comparable to that of the Mg\textsc{ii} \( \lambda 2800 \) doublet and is stronger than any other absorption feature. A careful examination of the possible contributors close to \( \lambda 3130 \), based on Moore (1959, 1962) tables and on the lists of atomic lines on the web sites of NIST\(^2\), UK\(^3\), and Kurucz’s\(^4\), confirmed that the sole candidates are the lines of singly-ionized metals of Fe\textsc{ii}, Cr\textsc{ii}, Ti\textsc{ii} and possibly V\textsc{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 other spectral regions of the nova. We just mention the case of the many strong lines of Cr\textsc{ii} arising from \( \chi = 2.5 \) eV. They may contribute to the observed \( \lambda 3130 \) feature with about five strong lines, but a similar or stronger contribution is expected close to \( \lambda \lambda 2840-2860 \) taking into account the shortward displacement, where many strong Cr\textsc{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\textsc{ii}: they contribute to the \( \lambda 3130 \) line with only a few lines of moderate intensity. A far stronger contribution is expected close to \( \lambda 2645 \) and in particular close to \( \lambda 2670 \) where many strong Fe\textsc{ii} lines are present, but the observed absorptions in the nova spectra at these wavelengths are similar or weaker than that close to \( \lambda 3130 \). Therefore, the main contribution to the 3130 feature in V838 Her does not originate from a blend of Cr\textsc{ii} and Fe\textsc{ii} lines.

- 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 blue-shifted absorption lines (Warner 2012; Schwarz et al. 2001). 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 \( \lambda \lambda 2350, 2580, 2660, 2750, \) and 2870 which are all shortward displaced in novae, they generally exhibit also the same pseudo-emission features close to \( \lambda \lambda 2640, 2900, 3000 \), 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

\(^2\) 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
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 modeling. 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 behavior close to $\lambda 3130$ and in nearby regions of a wide sample of 35 A-shell stars.

Table 3. A list of possible contributors by single-ionized ions to the $\lambda 3130$ absorption feature.

| Wavelength (Å) | ion | $A_{ij}$ (s$^{-1}$) | Level energy (eV) |
|----------------|-----|-------------------|------------------|
| 3111.597       | TiII| 2.667e+07         | 1.231332         |
| 3112.953       | TiII| 2.327e+07         | 1.224145         |
| 3115.200       | FeII| 6.384e+06         | 3.888695         |
| 3117.483       | FeII| 6.990e+06         | 3.891610         |
| 3119.550       | CrII| 1.713e+08         | 2.421358         |
| 3121.264       | CrII| 1.504e+08         | 2.434119         |
| 3125.879       | CrII| 8.186e+07         | 2.454790         |
| 3129.599       | CrII| 8.149e+07         | 2.434119         |
| 3132.961       | CrII| 8.151e+07         | 2.482828         |
| 3133.958       | FeII| 1.599e+06         | 3.888695         |

Our analysis indicates no evidence of strong absorption features close to $\lambda 3130$, 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 $\lambda 3130$ are easily identified as transitions of Cr II, opt.(5), and Fe II, with minor contributions by Ti III and V II, mainly from the complete Kurucz’s database. For all 35 objects the comparison between the absorption strength in a 30 Å wide region centered close to $\lambda 3130$ with the absorptions close to $\lambda 2750$ where many strong Fe II lines are present and $\lambda 2860$ where many absorption lines of Cr II from the same lower level as the lines close to $\lambda 3130$ are present, clearly shows that the absorption lines close to $\lambda 2750$ and $\lambda 2860$ are systematically more numerous and stronger than those close to $\lambda 3130$, and produce deeper absorptions than in the $\lambda 3130$ region. Instead, the contrary is observed in the spectrum of V838 Her: the $\lambda 3130$ absorption is far stronger than the other two. In A-shell stars we also observe a crowding of absorption lines close to $\lambda 2620-2640$, most of which are identified as Fe II and Cr II. However the same objects exhibit only weak absorptions close to $\lambda 3130$, see Fig. 3. On the contrary, in V838 Her the $\lambda 3130$ absorption feature is stronger than that close to $\lambda 2665$.

These findings are a clear proof of the presence of an additional strong absorption contribution close to $\lambda 3130$, unless a peculiar and unidentified spectroscopic mechanism acted to reinforce the absorption lines of Cr II and Fe II close to $\lambda 3130$ only in V838 Her, without reinforcing the other absorption lines of the same ions arising from the same or even lower terms.

- The PHOENIX models (Hauschildt et al. 1997) cor-
rectly reproduce the absorption features observed in the early IUE spectra of several novae but fail to reproduce the absorption feature close to 33130, 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).

- In the high resolution spectra taken in the early phase, despite of the uncertainty associated with the correction of the echelle orders close to 33130, there is a definite similarity between the profiles of the absorption features shortward of Mg II 32800 and 33130. If we refer to the nominal wavelengths of Mg II 32800 and 7Be II 33132, the lines exhibit a similar velocity field structure and similar velocity displacement close to -3000 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, that is, a resonance transition. Needless to say, there are no resonance lines close to the 33130 region except the 7Be II doublet 33132.

In conclusion, atomic data and observations indicate that the strong and wide absorption feature close to 33130 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 332660, 32750, 32860 and 33130 in A-shell stars and in V838 Her indicates that, on average, only a fraction of the 33130 absorption of V838 Her is produced by lines of the Fe-peak elements.

Therefore, we confidently identify the 33130 feature as due mainly to the Be II resonance doublet and assume that it is 7Be II λ (vac.) 33131.49 and λ (vac.) 33132.13 (hereinafter 7Be II 33132) on the basis of this detection, from narrow components, in other novae.

5 THE 7Be 33132 Å EMISSION LINE IN LATE SPECTRA

An emission feature centered close to 33130 is observed in the low resolution spectra taken in April 1991, 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 33133.70, 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 et al. (2007).

However, in the case of V838 Her the identification of the 33130 emission feature as the O III 33133.70 fluorescent line is improbable for these reasons:

- All UV and optical studies of V838 Her noted the absence or extreme weakness of the O III lines (Matheson

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et al. 1993; Starrfield et al. 1993; Vanlandingham et al. 1996; Schwarz et al. 2007). Downes et al. (2001), from a study of 96 novae, pointed out that V838 Her was an outlier in the sample because the [O\textsc{iii}] \lambda 5007 line was about 100 times fainter than all other novae. This can also be seen from Fig. 4 of Williams et al. (1994) and Fig. 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\textsc{iii} \lambda 1660-1666 emission lines, while other common emission lines, such as C\textsc{iv} \lambda 1550, N\textsc{iii} \lambda 1750, and C\textsc{iii} \lambda 1906, in a range of ionization that encompasses that of O\textsc{iii}, are clearly present (see Fig. 6).

This surprising peculiarity of V838 Her was pointed out recently.\footnote{\tt stsci.edu/~ofox/posters2017/posters/starrfield/poster.pdf} We considered the possibility that the absence of the O\textsc{iii} and [O\textsc{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\textsc{iii} are suppressed by collisional de-excitation. This is unlikely, because the UV O\textsc{iii} \lambda 1666 line has $n_e^{crit}$ of the order of $4.6 \times 10^{10}$ cm$^{-3}$, a value that is higher than that implied by the presence of the intercombination lines of N\textsc{iii} \lambda 1750 ($2 \times 10^{10}$ cm$^{-3}$), and C\textsc{iii} \lambda 1908 ($3.2 \times 10^{9}$ cm$^{-3}$), which are prominent in April spectra. Therefore, the faintness of the O\textsc{iii} lines is a consequence of the under-abundance of oxygen, in particular when compared to the abundance of carbon and nitrogen, (see Fig. 6)

- The BFM efficiency $\epsilon$ is defined as the fraction of the He\textsc{ii} Ly$\alpha$ photons which are converted to O\textsc{iii} photons, and can be estimated from the intensity ratio of a Bowen line (generally the $\lambda 3133.7$ line) to that of a He\textsc{ii} recombination line, e.g. $\lambda 1640$. In this case $\epsilon = 2.25 \times I_{3133.7}/I_{1640}$.

The data of Table 4, using the \texttt{numpy} (Van Der Walt et al. 2011), and the \texttt{astropy} (Astropy Collaboration et al. 2013) packages, and assuming that the $\lambda 3132$ emission were due to O\textsc{iii} $\lambda 3133.7$, would give a weighted average intensity ratio of O\textsc{iii} $\lambda 3133.7$ to He\textsc{ii} $\lambda 1640 = 0.17 \pm 0.03$. This would give an average conversion efficiency of $\epsilon = 0.38 \pm 0.10$. 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 $\tau$, in both the He\textsc{ii} and the O\textsc{iii} $\lambda 304$ resonance lines, and the efficiency is related to the optical depths of these resonance lines. This depends on the number of absorbers, i.e. nebular mass and elemental abundances and on the expanding velocity $v_{\text{exp}}$. 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 $\tau$. On the contrary,
Nova Her 91 has $v_{exp} \approx 3000-4000$ km s$^{-1}$ and a shell mass of $\approx 10^{-5} M_\odot$ (Schwarz et al. 2007; Vanlandingham et al. 1996).

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; Periaiah 2001; Dopita & Sutherland 2003).

From the observational side, Likkel & Aller (1986) noted that the optical depth of the Bowen OIII 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 $\epsilon \approx 0.30$ but here the lines are sharp and the large number of scatterings in
the resonance lines of He II and O III favours the conversion of He II λ3037.78 to O III λ3037.80 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 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 λ4304 resonance lines and compensates the negative effects of the expansion. The correlation between high abundances and BFM efficiency was noted by Netzer et al. (1985) in a study of BFM in 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 was overabundant in oxygen by a factor 25 and the expansion velocity was lower (v_{exp} ~ 1000 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 7Be 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 7Be 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, and 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 7Be ABUNDANCE ESTIMATE

We estimate the abundance of 7Be both by comparing the equivalent widths of the 7Be 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 7Be II λ3132 with those of Mg II λ2800, Hβ λ4861, and He II λ4680.

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 equivalent widths (EWs) of the 7Be II λ3132 (W(3132)) and Mg II λ2800 (W(2800)) absorption doublet. 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 (σ)^{-1} weighted average EW ratio of 1.80 ± 0.68, and a (σ)^{-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. Moreover, as explained by the considerations of Sect. 4, and Table 3, a minor but not negligible fraction of the measured EWs of the λ3130 line, that we estimate of the order of 10 to 20 percent, 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 7Be II λ312 over Mg II λ2800 must be accordingly reduced by a factor that, following McLaughlin (1941) precept of "errring 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) = 0.75 ± 0.25.

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

\[
W \propto N_i \times f_j \times \lambda^2
\]

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_j).

Since f_j(3132)/f_j(2800)=0.5 and W(3132)/W(2800)=0.75 ± 0.25, it follows that

\[
N_i(3132)/N_i(2800) = 1.20 ± 0.40
\]

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 eV and 15.04 eV, respectively), similar ionization fractions are expected. Thus, the above derived ratio also provides an estimate of the total 7Be/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 7Be abundance in V838 Her relative to hydrogen, by number, is given by:

\[
N(7Be)/N(H) = 3.8 \times 10^{-5} \times 1.20(±0.40) = 4.6 ± 1.5 \times 10^{-5}
\]

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 equivalent width 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_{out} is greater than 3000 km s^{-1}. Also, the similarity between two lines which 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 43000 Å the iron curtain effects are lower. Also, model atmospheres indicate that close to 43000 Å the local continuum is similar to that of the black body (see fig. 12 and 13 in Hauschildt et al. 1997). In any case, since the uncertainties regarding $^7$Be ii 3132 and Mg ii 2800 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 $^3$S132 line with those of the Mg ii 2800, Hβ 4861 and He ii 1640 lines. To use ratios of emission line intensities at different wavelengths the spectra must be de-reddened. Previous determination of the reddening E(B-V) from the literature are in the range 0.50 $\pm$ 0.10 mag (Vanlandingham et al. 1996; Kato et al. 2009).

We re-determined this quantity using the method based on the removal of the wide 42175 Å interstellar absorption bump. Using SWP and LWP spectra taken at the same epoch, and using the reddening curve of (Cardelli et al. 1989) we estimated a colour excess E(B-V)=0.45 $\pm$ 0.05 mag (Vanlandingham et al. 1996; Kato et al. 2009).

For $N_e$ $q_{12}$ $q_{21}$ 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 $N_e N_e q_{21}$ $N_e q_{21}$ one can neglect the second term in eq. (2) and assume that every collisional excitation is followed by a radiative decay. In this case the line emissivity is:

\[ I_{21} = N_1 N_e q_{12} h \nu_{12} = N_2 A_{21} h \nu_{12} \text{ erg cm}^{-3} \text{s}^{-1} \]  

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 $10^{14}$ el cm$^{-3}$, while $N_e$ in the nebula is of the order of $10^7 - 10^8$ el. 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:

\[ N_1 N_e q_{12} = N_2 A_{21} + N_2 N_e q_{21} \]  

### 6.2.1 The $^7$Be ii/Mg ii ratio

The emission lines of the resonance transitions of Mg ii 2800 and $^7$Be ii 3132 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.
\[ N(\text{Be II})/N(Mg II) = I_{3132}/I_{2880} \times (3132/2880) \times (q_{12}^{3132}/q_{12}^{2880}) \]

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

\[ q_{12} = (8.63 \times 10^{-6} \times \Omega_{12} \times e^{-\Delta E/\kappa T_e} )/(q_{12} \times T_e^{-1/2}) \]

where \( q_{12} \) is the statistical weight \((2J+1)\) of the lower level of the transition, \( T_e \) is the electron temperature, \( e^{-\Delta E/\kappa T_e} \) is the Boltzmann factor and \( \Omega_{12} \) 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 \( \Omega(3132) = 11 \pm 4 \) as a weighted average of several estimates (see Appendix A). Substitution of this value in the previous relation, with \( T_e = 10000 \) K (0.861 eV), \( \Delta E = 3.96 \) eV, provides \( q_{12}^{3132} = 4.36 \times (1.7) \times 10^{-9} \).

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 \( \Omega(2880) = 16 \pm 2 \) which, after substitution in the previous relations with \( T_e = 10000 \) K (0.861 eV) and \( \Delta E = 4.43 \) eV, provides \( q_{12}^{2880} = (3.43 \pm 0.9) \times 10^{-9} \).

Incidentally, it is worth pointing out that the reported under-abundance 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 \( T_e = 10^4 \) which is usually assumed.

For the April spectra using the data in column 4 of Table 3 and the above mentioned \texttt{numpy} (Van Der Walt et al. 2011) python package we derived a \((\sigma)^{-1}\) weighted average emission ratio \( I(3132)/I(2880) \approx 0.80 \pm 0.26 \) (or \( 0.67 \pm 0.134 \) in the case of a \((\sigma)^{-2}\) weight). From these values and the previous relations we find that the relative \( N(\text{Be II})/N(Mg II) \) number ratio is \( \sim 0.90 \pm 0.46 \), where the final error originates from the propagation of the error in the emission intensity ratio and in the effective collision strengths, \( \Omega_{12} \), for the Mg II 2800 and Be II 3132 transitions.

The two ions have similar ionization potential and we can safely assume that \( N(\text{Be})/N(Mg) \approx N(\text{Be II})/N(Mg II) \). 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 \(^7\text{Be}\) in the ejecta, compared to hydrogen in the Sun (by number) is

\[ N(\text{Be})/N(H) = 3.4(\pm 1.7) \times 10^{-5} \]

For the correction by the decay of \(^7\text{Be}\), see Sect. 6.2.4.

6.2.2 The \(^7\text{BeII} \lambda 3132/\text{H}\beta \) ratio

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

- Schwarz et al. (2007) reported a ratio \( \text{He II} \lambda 1640 \) over \( \text{H\beta} \). \( I_{1640}/I_{4861} = 6.9 \) for April 22, 1991, but did not provide the intensity of H\(\beta\). Since an IUE SWP spectrum of the same date is available, using this ratio one could estimate the intensity of H\(\beta\). 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\(^{-1}\).

- Williams et al. (1994) found \( I_{4861}/I_{4686} \sim 0.5 \) in April 25. Since the expected theoretical ratio \( I_{1640}/I_{4686} \sim 7.0 \) (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. 22 April) one expects a higher \( I_{4861}/I_{4686} \) ratio, and so a value of \( I_{4861} \) close to \( 5.0 \times 10^{-12} \) 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.

Another constrain to 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):

\[ N(\text{Be II})/N(H^+) = 3132/4861 \times (\alpha_{4861}^{3132}/q_{12}^{3132}) \times I_{3132}/I_{4861} \]

For \( T_e = 10000 \) and log \( N_e = 6-7 \), the effective recombination coefficient is \( \alpha_{4861}^{3132} \approx 0.05 \times 10^{-13} \) cm\(^3\) s\(^{-1}\), with small variations about these values of \( T_e \) and \( N_e \) (Osterbrock & Ferland 2006). Since \( q_{12}^{3132} = 4.36 \times (1.74) \times 10^{-9} \) we find

\[ N(\text{Be II})/N(H^+) = 3.6 \sim (\pm 2.4) \times 10^{-6} \]

The above reported value is probably a lower limit for the \(^7\text{Be}\) abundance because at this epoch some \(^7\text{Be}\) is also in the \(^7\text{Be}^{+}\) ionization stage (\(^7\text{Be}^{++}\) 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 H\(\beta\), and from that of the effective collision strength \( \Omega_{12} \) for the \(^7\text{Be II} \lambda 3132 \) transition. This apparent value for April 22 must be corrected for the decay of \(^7\text{Be}\), see Sect. 6.2.4.

6.2.3 The \(^7\text{BeII} \lambda 3132/\text{He II} \lambda 1640\) ratio

Another constrain to the \(^7\text{Be}\) 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:

\[ N(\text{Be II})/N(\text{He II}) = I_{3132}/I_{1640} \times 3132/1640 \times \alpha_{eff}^{1640}/q_{12}^{3132} \]

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

\[ \alpha_{eff}^{1640} = 8.1 \times 10^{-13}, \quad q_{12}^{3132} = 4.36(\pm 1.7) \times 10^{-9} \]
and of the average \( I_{3132}/I_{1640} \) ratio = 0.20 ± 0.05 gives:

\[
N(7\text{Be})/N(\text{HeI}) = 7.1(±3.3) \times 10^{-5}.
\]

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

It appears, however, that helium is mostly HeII as results from the ratio \( \text{HeII}(1640)/\text{HeI}(5876)=35 \) in April 22 (Schwarz et al. 2007). In this case (helium mostly HeII), from the above related report, 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, (that is, \( \text{He}/\text{H} \sim 0.14 \)), we derive a lower limit:

\[
N(7\text{Be})/N(H) = 1.0(±0.45) \times 10^{-5}.
\]

See Sect. 6.2.4 for the correction for the decay of 7Be.

### 6.2.4 The average 7Be and 7Li abundances

The observed abundance of 7BeII 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 days is almost negligible for the early absorption spectra taken a few days after the outburst. Instead, it is, on average, by a factor \( \approx 1.30 \) for the abundances found in April from the emission line ratio \( I_{3132}/I_{2800} \) of 7BeII/MgII, and \( I_{3132}/I_{1640} \) of 7BeII/HeII (from day 12 to day 29), and by a factor 1.36 for the abundance from the ratio \( I_{3132}/I_{1650} \) of 7BeII/HI 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 7Be/H ratio of approximately \( \approx 2.5 \times 10^{-5} \) (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 7BeII/MgII ratio).

This corresponds to an overproduction of 7Be 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 & Jose (1998) which indicate an average mass ratio 7Be/H close to \( 2 \times 10^{-5} \) and \( 4 \times 10^{-6} \), respectively.

Since 7Be all converts into 7Li the corresponding 7Li/H ratio (\( \approx 2.5 \times 10^{-5} \), by number) indicates an overabundance by about 4 dex over the 7Li meteoritic value \( 7\text{Li}/\text{H} = 1.86 \times 10^{-9} \) (Asplund et al. 2009; Lodders et al. 2009), that is an overproduction by about 1 dex over the models of Jose (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 V5658 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 7Li/H mass ratio is \( \approx 1.7 \times 10^{-4} \), assuming \( m(\text{H})/m(\text{tot}) \sim 5.6 \times 10^{-1} \) (Schwarz et al. 2007), then the total ejected mass of 7Li is of about 9.5 \( \times 10^{-10} \, M_{\odot} \).

## 7 DISCUSSION

The possibility of the synthesis of 7Be and of its transport during outburst to the outer nova layers in a process similar to the 7Be-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); Jose (2016) for a comprehensive review and detailed considerations on this subject.

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

The hydrodynamic simulations with a full reaction network of Hernanz et al. (1996), and José & Hernanz (1998) confirmed the feasibility of the 7Be transport mechanism in nova outburst. Hernanz & José (2000); José (2002); Hernanz & José (2004) also found that CO novae are favoured in comparison with ONe novae for 7Be synthesis because their faster rise-evolution to \( T \approx 10^{9} \, K \) the early outburst phases, driven by their larger amount of \( ^{12}\text{C} \) content, favours 7Be survival: 7Be destruction through the deadly \( p \)-capture reactions is prevented due to the efficient role played by the inverse photo-disintegrations on \( ^8\text{Be}(y,p)^7\text{Be} \) (José & Hernanz 2007; Isern et al. 2011; Jose 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 et al. 2016).

In the specific case of the 7Be-transport mechanism, the observation of 7Be and 7Li requires that 7Be has to be transported by convection to low-temperature zones in a short timescale. Therefore, the observed abundance of 7Be and \( ^7\text{Li} \) in the ejecta is sensitive to the rate at which it is transported to the outer, cooler layers prior to its decay to 7Li (see Starrfield, Iliadis & Hix in Bode & Evans 2012) and see also Isern et al. (2011). Regrettably, the efficiency of

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

| Stage     | Method     | 7Be/H   |
|-----------|------------|---------|
| Abs.      | \(^{7}\text{Be}(3132)/\text{MgII}(2800)\) | 4.6(±1.5) \times 10^{-5} |
| Em.       | \(^{7}\text{Be}(3132)/\text{MgII}(2800)\) | 4.4(±2.2) \times 10^{-5} |
| Em.       | \(^{7}\text{Be}(3132)/\text{HeII}(1640)\) | 1.3(±0.6) \times 10^{-5} |
| Em.       | \(^{7}\text{Be}(3132)/\text{HI}(4861)\) | 0.5(±0.4) \times 10^{-5} |
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 & Jose 1998) and so about $1 \times 10^{-10} - 1.2 \times 10^{-11}$ $M_\odot$ of $^7$Be were ejected in a CO and a ONe nova respectively.

Wanajo et al. (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 $T_{\text{peak}} \sim 3-4$ times $10^8$ K, but they found that for the same $T_{\text{peak}}$ 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:

- The presence of a massive CO nova ($M_1 \leq 1.15$ $M_\odot$) is required by models (Hernanz & Jose 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.

- 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 $M_\odot$, that is, 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 abundant nuclei (Jose et al. 2004; Hernanz & Jose 2005).

As noted in Sect. 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, modeling of the outburst of V838 Her (Downen et al. 2013; Champagne et al. 2014) indicated a massive (1.34-1.35 $M_\odot$) ONe WD, without compelling evidence for breakout ($T_{\text{peak}}$ in the TNR close to $3 \times 10^8$ 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 which 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 Tajitsu et al. (2016); Molaro 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

- 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. For the first time the resonance line of $^7$Be ii is also detected in emission;

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

- Since $^7$Be all converts into $^7$Li the corresponding $^7$Li/H ratio ($= 2.5 \times 10^{-5}$, 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 Jose (2016);

- 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 $\times 10^{-10}$ $M_\odot$.

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 el 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| $1.9 \times 10^{-5}$ | 1   |
| V5668 Sgr | CO   | 58  | -1175| $1.7 \times 10^{-4}$ | 2   |
| V2944 Oph | CO   | 80  | -645 | $1.6 \times 10^{-5}$ | 4   |
| V407 Lup | ONe  | 8   | -2030| $6.2 \times 10^{-5}$ | 3   |
• 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. (Jose 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).

• 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) and (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.

• 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.

• Jose & 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 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\,\textsuperscript{ii} \(\lambda 3132\) AND Mg\,\textsuperscript{ii} \(\lambda 2800\)

The effective collision strength \(\Omega\) of the Be\,\textsuperscript{ii} \(\lambda 3132\) resonance transition is not commonly listed in astrophysical literature. Osterbrock & Ferland (2006) and Dopita & Sutherland (2003) provide collision strengths for the \(2s - 2p (2^S - 2^P^o)\) transitions for ions of the Li\,\textsubscript{i} iso-electronic sequence (i.e. C\,\textsuperscript{iv}, N\,\textsuperscript{v} and O\,\textsuperscript{vi}) but not for Be\,\textsuperscript{ii}. Extrapolation to Be\,\textsuperscript{ii} of the tabulated values for the CNO ions indicates \(\Omega \approx 10-12\). Other estimates can be found in literature both from various atomic models and from experimental cross sections, resulting in a range of values for \(\Omega\) for Be\,\textsuperscript{ii}; an assessment of collision strengths for lithium-like ions was made by McWhirter (1994), using \(\Omega\) values based on the experimental cross section by Taylor et al. (1980) and Mitroy & Norcross (1988). Extrapolation of these values to KT \(\sim 1\) eV indicates \(\Omega \sim 10\). The Los Alamos theoretical on-line tables \(^6\), for KT \(\sim 4\) eV, indicate \(\Omega \approx 12\), while the Universal Fit Formula of Cochrane & McWhirter (McWhirter 1994) indicates \(\Omega \sim 14\). In this study we assume \(\Omega(3132) = 11 \pm 4\) 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 iso-electronic sequence, there is a long standing discrepancy for Be\,\textsuperscript{ii} (Dere et al., 1997).

For Mg\,\textsuperscript{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 (2000) and Sigut & Pradhan (1995). The Los Alamos theoretical estimates give \(\Omega \sim 20\), 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 \(\Omega(2800) = 16 \pm 2\) as a weighted average of these values.

\(^6\) http://aphysics2.lanl.gov/tempweb/lanl/