The ambiguous transient ASASSN-17hx

A possible nova-impostor

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ABSTRACT

Aims. Some transients, although classified as novae based on their maximum and early decline optical spectra, cast doubts on their true nature and whether nova impostors might exist.

Methods. We monitored a candidate nova which displayed a distinctly unusual light curve at maximum and early decline through optical spectroscopy (3000-10000 Å, 500 < R < 100000) complemented with Swift UV and AAVSO photometry. We use the spectral line series to characterize the ejecta dynamics, structure, and mass.

Results. We found that the ejecta are in free ballistic expansion and structured as typical of classical novae. However, their derived mass is at least an order of magnitude larger than the typical ejecta masses obtained for classical novae. Specifically, we found \( M_e \geq 9 \times 10^{-3} M_\odot \), independent of the distance for a filling factor \( \varepsilon \approx 1 \). By constraining the distance we derived \( \varepsilon \) in the range 0.08-0.10, giving a mass \( 7 \times 10^{-4} \leq M_e \leq 9 \times 10^{-4} M_\odot \). The nebular spectrum, characterized by unusually strong coronal emission lines, confines the ionizing source energy to the range 20-250 eV, possibly peaking in the range 75-100 or 75-150 eV.

Conclusions. We link this source to other slow novae which showed similar behavior and suggest that they might form a distinct physical sub-group. They may result from a classical nova explosion occurring on a very low mass white dwarf or be impostors for an entirely different type of transient.

Key words.
Table 1. Epoch of the VLT (Very Large Telescope)/UVES (Ultraviolet and Visual Echelle Spectrograph) observations and the adopted instrument setups. In all cases the CCD readout was "fast readout", "low gain", and un-binned. In columns 4, 6 and 7, whenever two values are given, the first refers to the blue arm and the second to the red-arm. Note that the resolving power (R) of the red arm depends also on the CCD, within the 2 CCD mosaic (e.g. 95000 and 100000).

| UT date | age (d) | UT start (hr) | exptime (s) | inst. setup | slit (") | R         |
|---------|---------|---------------|-------------|-------------|----------|-----------|
| 2017/08/17 | 56      | 01:59         | 1000        | DIC1 346+564 | 0.4/0.3  | 650000/95-100000 |
| 2017/08/17 | 56      | 02:21         | 500         | DIC2 437+760 | 0.4/0.3  | 650000/95-100000 |
| 2017/08/23 | 64      | 02:20         | 1100        | DIC1 346+564 | 0.8      | 60000     |
| 2017/08/23 | 64      | 02:43         | 400/300     | DIC2 437+760 | 0.8      | 60000     |
| 2017/09/19 | 89      | 01:24         | 1100        | DIC1 346+564 | 0.8      | 60000     |
| 2017/09/17 | 89      | 01:51         | 400         | DIC2 437+760 | 0.8      | 60000     |
| 2017/10/30 | 132     | 00:34         | 1100        | DIC1 346+564 | 0.4/0.3  | 650000/95-100000 |
| 2017/10/30 | 132     | 00:59         | 400         | DIC2 437+760 | 0.4/0.3  | 650000/95-100000 |

Table 2. The log of the observations for the ARAS spectra published in this work: the top 8 spectra are the low resolution flux calibrated spectra shown in Fig.10, the bottom 17 spectra are the higher resolution data used to produce Fig.10.

| UT date   | age (d) | UT start (hr) | exptime (s) | R       |
|-----------|---------|---------------|-------------|---------|
| 2017/07/01 | 12      | 20:45         | 9149        | 598     |
| 2017/07/10 | 21      | 20:18         | 8050        | 525     |
| 2017/07/31 | 42      | 19:48         | 5454        | 580     |
| 2017/08/09 | 51      | 19:45         | 6618        | 580     |
| 2017/08/13 | 55      | 19:45         | 6181        | 580     |
| 2017/08/23 | 65      | 19:06         | 5403        | 530     |
| 2017/09/04 | 77      | 18:50         | 6094        | 580     |
| 2017/09/08 | 81      | 18:43         | 4362        | 580     |

Table 3. Log of observations for the transition stage spectra. The top two lines refer to the LISA spectra, the bottom one to the TIGRE (Teleescoipo Internacional de Guanajuato Robotico Espectroscopico)/HEROS (Heidelberg Extended Range Optical Spectrograph) spectrum.

| UT date   | age (d) | UT start (hr) | exptime (s) | R       |
|-----------|---------|---------------|-------------|---------|
| 2018/03/30 | 284     | 16:42         | 1813        | 1400    |
| 2018/05/29 | 344     | 12:06         | 1998        | 1400    |
| 2018/09/25-26 | 462,463 | 01:20 | 7200×2   | 20000   |

for each of the selected ARAS spectra are reported in Table 2. We note that the ARAS data are available in reduced form and that the data reduction process followed by the group is the standard procedure.

Late spectra were taken ~9 and 11 months after outburst by one of us (TB) in low-resolution mode (LISA spectrograph on a 0.28 m Celestron telescope) together with broadband photometry (B, V) and have been complemented with mid-resolution spectra taken at the Heidelberg robotic telescope TIGRE with HEROS, almost 15 months after outburst (see Table 3). Note that LISA spectra were reduced following the same standard procedure outlined in the ARAS web pages and calibrated in flux through simultaneous photometry observations. The HEROS spectra, although pipeline processed according standard procedures, were not flux calibrated.

The last sequence of spectra consists of two NOT/FIES (Telting et al. 2014, Frandsen & Lindberg 1999) spectra taken about two years after outburst with the aim of observing the optically thin nebular phase of the object (see Table 4). The data were reduced with the instrument pipeline at the telescope. The observing strategy envisioned for the instrument did not include background subtraction (there is no dedicated sky-fiber in mid-resolution mode), since it is expected to be insignificant. We verified this with a 900 sec sky exposure in which both the exposed and the masked part of the CCD showed the same count level, and with the science exposure whose inter order background roughly matched that of the sky exposure. We therefore ascribe only a few percent uncertainty to the flux calibration process in the absence of sky subtraction with FIES. We note that the largest systematic effect is introduced by the reddening correction (see Section 2.1).

Of the two FIES epochs, the May spectrum was contaminated by stray light (John Telting, private communication) that affected the background level redward of 6400 Å. Therefore, any physical parameter derived in the following sections relies on the data taken during the July run, which happened after the installation of a new light-leak baffle around the spectrograph shutter. During the July run, however, we experienced a color loss between the first and following two exposures. Specifically, we found up to 30% loss in the blue part of the spectrum (Hγ, 4363 Å), and only ~5% at Hα and 7065 Å, in the line flux of the second and third exposure compared to the first. This happened because the spectrograph atmospheric dispersion corrector (ADC) is set at the beginning of the sequence and not updated during subsequent exposures. Since the target crossed the meridian after ~2/3 of the first exposure, the first exposure should have suffered differential color losses as well. Thus, our derived den-
The good match in the structure with the interstellar absorption from Na I and Ca II in the local standard of rest (LSR) frame. The high signal-to-noise and resolution of the UVES spectra allow us to use the interstellar absorptions to estimate the reddening. The spectra show multiple saturated Na I D and Ca II H&K interstellar components, indicating that 17hx is significantly reddened. The saturation of the Na I D absorption lines prevent using the Munari and Zwitter (1997) EW(Na I D)-E(B-V) relation. The much weaker and resolved K I absorptions are, however, blended with telluric absorptions so that using the analogous relation for the potassium resonance line provides only a lower limit: E(B-V) > 0.4 mag.

Fig. 1 displays the antenna temperature profile of the neutral H from the LAB 21 cm maps (Kalberla et al. 2005) together with the interstellar absorption from Na I and Ca II in the local standard of rest (LSR) frame. The good match in the structures support using of the H I column density to estimate the E(B-V) following Bohlin et al. (1978). Specifically, integrating the H I temperature in the velocity range [-20,+125] km/s (i.e. the velocity range spanned by the sodium and calcium absorptions), we derive E(B-V) = 0.71 ± 0.02 mag, where the uncertainty is purely statistical. This is the reddening we apply to all spectra in the following analysis. We note that the adopted E(B-V) agrees with the values derived by Munari et al. (0.68 mag, 2017a) and by Kuin et al. (0.8 ± 0.1 mag, 2017), within the errors.

All figures in this work were created using the observed spectra (i.e. not corrected for reddening). We applied the reddening correction ahead of any physical parameter derivation (Section 6.2).

3. Data Analysis: the light curves

Fig. 2 shows the 17hx light curves in the filters B,V,R and I, obtained from the AAVSO database (Kafka 2019), together with the epochs of the spectroscopic observations listed in Tables 1-4 (top and mid panels). The bottom panel of Fig. 2 displays the color curves. The middle panel of Fig. 2 also displays the sparse UV photometry obtained by Swift. The UV photometry is also listed in Table 5 including data points that are outside the plotted time intervals.

The optical photometry strikingly shows that 17hx light variations are exceptional in both amplitude and timescale. Brightness variations of CNe during maximum rarely exceed 1-1.5 magnitudes, while their time scales never extend beyond a couple of weeks. Here the amplitudes are > 2 mag on a timescale of 1-2 months. The amplitudes are greater in the V band.

The UV photometry, instead, is possibly suggestive of flux redistribution since the UVM2 flux displayed a drop during the first ~50 days, while the optical flux increased. Unfortunately, because of the limited number of UV observations we cannot be conclusive. As of today, flux redistribution has been convincingly shown only for nova Cyg 1992 (Shore et al. 1994).

The color light curves (Fig. 2, bottom panel), show B-V, V-R and V-I colors that are in low amplitude anti-phase with respect to the broad band light curves; 17hx seems redder during the minima than the maxima. However, spectroscopy shows (see Section 4) that the continuum SED is redder at maximum than at minimum. The color variation and in particular the V-I and B-V color maxima are driven by the strong emission lines during the photometric minima.

Although less pronounced, similar behavior is not uncommon among classical novae (e.g. nova Cen 2013 and nova Sgr 2015b; see AAVSO light curves for the photometry and Mason et al. 2018 for nova Cen spectroscopy; nova Cen and nova Sgr 2015b spectra are publicly available in the ESO archive), and highlight the potentially misleading inferences from photometry alone.

4. Data Analysis: early spectroscopy, the optically thick stage

4.1. The high resolution UVES spectra

The four UVES spectra cover the first decline and minimum after the first optical maximum, the second maximum, and the decline after the fourth maximum (see Fig. 2). They therefore permit a comparison in great detail (R≥60000) of spectral characteristics at the different photometric states providing important information about the gas kinematics and physics.

At all epochs, the emitting gas is dominated by H I (from the Balmer and the Paschen series, see Fig. 3 and low ionization potential metal lines, mainly Fe II (e.g. Revised Multiplet Table, RMT, 73, 40, 46, 55, 56, 49, 48, 41, 42, 35, 47, 37, 38, 27 and 28) but also Ca I (RMT 2) and II (H&K and the NIR triplet). Non-metal transitions are also present, e.g. O I (RMT 1 and 4),

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**Table 4.** Epoch and instrument setup for the NOT (Nordic Optical Telescope)/FIES (Fiber fed Echelle Spectrograph) observations. The choice of fiber bundle 3 med-red, corresponds to a resolving power R = 46000.

| UT date  | age (d) | UT start | exptime | setup     |
|----------|---------|----------|---------|-----------|
| 2019/05/28 | 907     | 02:49    | 2200s×3 | F3 med-res |
| 2019/07/21 | 762     | 23:19    | 2650s×3 | F3 med-res |
Fig. 2. Top panels: the AAVSO V light curve together with the epoch of the UVES (blue lines), ARAS (green dotted and solid lines, representing respectively the high resolution un-calibrated and low resolution flux calibrated spectra), the LISA and HEROS observations (red lines) and the FIES spectra (cyan lines). Mid panel: the AAVSO B, R, and I light curves together with the Swift UVOT UVW1 ($\lambda_{c}=2600$ Å), UVM2 ($\lambda_{c}=2246$ Å), and UVW2 ($\lambda=1928$ Å). Bottom panel: the color light curve: (B-V), (V-R) and (V-I). Error bars ≥0.2 mag in the color light curves were arbitrarily set whenever either the V or the paired broad band photometry had not associated error bar. Colors were computed every time the V and broad band filter were taken within 3 hr observations.

Apart from that, the three minimum/decline spectra are similar to each other but very different from that at maximum. In particular, the minimum and decline spectra display a flat continuum, strong emissions with rectangular shape profile partially resolved into numerous structures (i.e. "castellated" tops), and weak or absent absorption components. Conversely, the maximum spectrum displays a redder continuum, weak emission components with a smooth profile and strong P Cyg-like absorptions (see Figs. 3, 4, and 5). The difference in the emission line profiles suggests that, during minima, only a small number of structures is contributing to the emission component; while, at maximum, many more structures contribute to the emission creating a blended profile.

Most important, the ionization degree of the emitting gas changes with the photometric oscillations and is higher at minima than at maximum. This is best illustrated by the changes in the He I lines (see Fig 6). The weakness of the emission component during the maximum indicates reduced He* recombination, yielding insufficient emission measure for detection. The velocity displacement of the absorption, instead, indicates that during maximum the absorption (of high energy photons) is confined to the low velocity regions of the gas. In other words, larger volumes and higher velocities are involved in the He* recombination during minima.

The Ca transitions confirm this trend (see Fig 5). The strengthening of the narrow absorption at ∼460 km/s, together with the appearance of a much broad and deep absorption component at ∼660 km/s in both Ca I and Ca II transitions indicates more neutral Ca and Ca* at maximum than at minimum. During the photometric minima the Ca is largely twice ionized, given that the Ca* ionization potential (IP) is $\lesssim 12$ eV, i.e. less than that of H0, Fe* and much less than that of He0.

Neutral silicon, an intermediate ionization potential element (IP=8 eV), displays analogous behavior to the Fe II transitions (see Fig 7). Like the optical iron multiplets, the Si II doublet is a transition between two excited levels, specifically 4s and 4p. The lower level 4s is connected to the ground state by resonance transitions ($\lambda1533,1526$). To produce $\lambda6347,6371$ emissions and
absorptions, the resonance UV transition must be optically thick with low collisional de-excitation of the 4p level. This suggests an electron density $n_e \approx 7 \times 10^{14}$ cm$^{-3}$. Again, the strong broad absorption visible at maximum suggests that at this time there is more Si$^7$ than at minima when it is likely twice ionized. The Si II disappears in the last UVES spectrum, suggesting that the gas has diluted to the point that the UV doublet $\lambda 1553, 1526$ is no longer optically thick and thus incapable of overpopulating the 4s level. We exclude that the Si$^+$ further ionized into Si$^{2+}$ since the IP for Si$^+$ is about the same as Fe$^+$ ($\sim 16$ eV) and Fe II transitions are still present in the last UVES spectrum.

Finally, O I is detected only in the RMT triplets (1) and (4). They are interesting for their remarkably different profiles. The RMT triplet (1) ($\lambda 7772, 7774, 7775$) forms mainly via recombination cascade of O$^+$. It can display absorption components because its lower level leads to the ground state through an intercombination transition. In contrast, RMT triplet (4) (centered around $\lambda 8446$), is mainly produced by optically thick H Ly$\beta$ transition that pumps the upper level of the OI $\lambda 1025$ and, by cascade, populates the upper level of the $\lambda 8446$ triplet and explains the occasionally strong absorption component). Neutral oxygen has nearly the same ionization potential energy as H ($\sim 13$ eV) and the $\sim 17774$ triplet has a similar profile to the Balmer lines (see Fig 8 where the triplet is plotted together with the H$\delta$ transitions, top panel). The hydrogen and oxygen recombine together with just small local differences. The $\lambda 8446$ triplet, in contrast, shows only emission whose profile matches the Fe II and Si II transitions at minima, but displays almost pure absorption at maximum. Like Fe II and Si II, the $\lambda 8446$ triplet results from UV pumping that is favored by the high UV opacity of the "iron curtain".

In summary, at minimum the ionization state of the gas increases displaying stronger, structured emission profiles and higher velocity absorptions in the high IP energy transitions, but null or weak absorption in the low IP energy transitions. In contrast, at maximum the gas recombines, the average emission measure within each transition diminishes, and the photoexcitation is confined to the low velocity range (the lower deep absorptions of the maximum P Cyg profiles).

4.1.1. The narrow absorption at around -460 km/s

All the UVES spectra display a narrow absorption at $\sim 460$ km/s that is present in all transitions (H I, Fe II, Ca I and Ca II, Si II,
Table 5. Swift UV photometry. Columns 2 and 3 have been rounded to the closest integer; 4 and 5 to the second decimal.

| MJD    | age (d) | exptime (s) | mag   | mag err | filter |
|--------|---------|-------------|-------|---------|--------|
| 57934.272744 | 11      | 147        | 13.87 | 0.04    | UVM2   |
| 57934.339648 | 11      | 107        | 13.85 | 0.04    | UVM2   |
| 57966.028409 | 43      | 129        | 15.37 | 0.06    | UVM2   |
| 57966.096473 | 43      | 127        | 15.55 | 0.07    | UVM2   |
| 58234.180839 | 311     | 187        | 13.50 | 0.03    | UVM2   |
| 58234.374123 | 311     | 149        | 13.56 | 0.03    | UVM2   |
| 58743.536150 | 820     | 228        | 15.55 | 0.05    | UVM2   |
| 58746.780652 | 823     | 102        | 15.51 | 0.08    | UVM2   |

Fig. 4. Evolution of the Fe II λ5169 (RMT 42) transition. Y axis units are erg/cm^2/s/A. The blue and red dotted lines mark the velocity of the persistent narrow absorption (see Section 4.1.1) and of the He I absorption in the first UVES spectrum, respectively (see text for details) for a comparison. The photometric state (min, max) of each spectrum is indicated within each panel.

K I, O I) except those of He I (see the blue dotted line in Figs 5, 7 and 8). It persists also when other absorption components disappear. Although this could be consistent with circumstellar gas, we exclude this explanation for the following reasons. Absorptions from excited and/or metastable levels (as in the case of Fe II and Ca II NIR) would imply unusually large column densities. Similarly, the detection of the narrow absorption in the O I λ7774 and H Balmer transitions would require that the central object is sufficiently powerful to ionize the circumstellar environment that is more than 114 AU 2.4 × 10^18 erg away from the transient since it is dynamically undisturbed at day 132. Figs 4, 5 and EW measurements show that the narrow absorption is stronger at maximum and weaker at minimum; i.e. it varies responding to the radiation field in phase with the rest of the ejecta. This requires similar physical conditions in the narrow absorption region and the ejecta. Hence, the narrow component originates in the ejecta and its persistence informs about the gas kinematics, specifically, that it is in ballistic expansion (v ∼ r) as typical for explosive processes. The emitting gas is not a wind and is not a pulsating pseudo-photosphere but an ejecta similar to CNe.

4.2. The low and medium resolution ARAS spectroscopic sequences

The ARAS spectra listed in Table support and extend our finding from the UVES spectra. Fig shows the evolution of the SED, uncorrected for reddening, and of the emission lines across the first photometric cycle. 17hx displays a flat continuum and strong emission lines with weak or no (i.e. not resolved) P Cyg-
Fig. 5. Evolution of the Ca I and Ca II line profiles (see text for details). Note that the emission centered at about +500 km/s in the first column (Ca I panels) is from Fe II RMT 27. The arrow in the third panel from top indicates the second broad absorption from Ca I λ4226. The Y axis units are erg/cm²/s/Å. The blue and red dotted lines mark the velocity of the persistent narrow absorption (see Section 4.1.1) and of the He I absorption in the first UVES spectrum, respectively. The photometric state (min, max) of the spectra is indicated on the left of each row.

The similarity of the line profiles at minimum and decline or maximum and rising phases is more evident in Fig.10 which displays the evolution of Hα, Hβ, He I λ5876 (blending at any time with Na I D both of ejecta and interstellar origin), and Fe II λ5169. The spectra are normalized to the continuum. What emerges from the figure is:

1. the emission line component in each transition at minimum is always at least an order of magnitude stronger than at maximum;
2. the Hα and Hβ profiles are remarkably different (especially from day +74 on), indicating that the lines are very optically thick;
3. within each cycle, the line profiles change from a strong emission flanked by a weak P Cyg absorption to a weak emission with a strong P Cyg absorption. However, on subsequent cycles the emission component both strengthens and broadens;
4. the emission profiles differ systematically in structure depending on the photometric state, showing rectangular and castellated forms, especially in the low ionization potential energy transitions, during the minima and smoother and featureless profiles at maxima.
5. high ionization potential energy species (e.g. He + which recombining produces He I lines) display no emission during maxima and detectable emission during minima. In addition, their absorption component (which is always single and shallow) moves outward and inward at minima and maxima respectively.

Both Fig.9 and Fig.10 show that the degree of ionization of the emitting gas increases at minima with respect to maxima while the continuum becomes bluer.

5. Data Analysis: late low and medium resolution spectroscopy, the transition stage

The two LISA low resolution spectra taken during March and May 2018, 284 and 344 days after outburst, are similar to each other and show a highly opaque emitting region (see Fig.11 top panel). Hα is one order of magnitude stronger than Hβ in the observed spectrum (10⁻¹⁰ vs 9×10⁻¹² erg/cm²/s/Å, respectively).
Fig. 6. Evolution of the He I (triplet and singlet) transitions (see text for details). Y axis units are erg/cm²/s/Å. The red dotted line mark the velocity of the absorption component at the first epoch: ∼1050 km/s. The photometric state (min max) is indicated on the left of each row.

or a factor 5.3 stronger when dereddened. The strongest emission lines after the Balmer series are He I, especially the triplets (e.g. λ5875 and 7065 Å); while He II λ4685 and the Bowen blend at 4640 Å are weakly present. Weak forbidden transitions, such as [Ne III] λ3968, [N II] λ5755 and [O III] λ5007, 4959 and 4363, are also present and evince the thinning of the gas. The [O III] emissions are particularly weak and the λ5007 is blended with the strong He I λ5015 producing a line centered at 5011 Å. Even neglecting the He I contribution to such a blend, the electron density resulting from the [O III] line ratio (e.g. Osterbrock 1989, adopting T_e ∼10000 K) is >10⁷ cm⁻³, i.e. much greater than the critical value (~7×10⁶ cm⁻³ for the [O III] RMT 2 and a few ×10⁵ cm⁻³ for the RMT 1; Osterbrock 1989). Other weak emission lines are [O I] λ6300, 6364 and possibly Si II λ6347. Weak unidentified emission lines are detected at 5159 Å, 5267 Å, and 5315 Å. These cannot be coronal emission from, e.g., [Fe VI], [Fe VII], [Fe VII] respectively, since they are absent in the following HEROS spectra. They cannot be Fe II, since the stronger multiplets (e.g. multiplet 42, 48, 49) should also be present; they are not, nor are there any detectable [Fe II] transitions.

The higher resolution HEROS spectrum (day 462, Aug 20 2018; see Fig 11 bottom panels), although not flux calibrated, can be used to confirm the line identification of the LISA spectra and that the unidentified lines have disappeared. The higher resolution spectrum also reveals some differences in the line profiles. In particular, the forbidden transitions display relatively stronger wings (up to ∼±1200 km/s), indicating that they arise in the high velocity, lower density peripheral regions of the ejecta.

6. Data Analysis: late high resolution spectroscopy, the optically thin stage

The two FIES spectra, taken about 2 years after outburst, are separated by only ∼2 months. The spectra are quite similar and display the same species and transitions, in line with the slow evolution of 17hx. We show only the July 2019 spectrum in Fig 12 since it was not contaminated by scattered light (see Section 2). In both spectra, the strongest emission lines are still those of the H Balmer series. The forbidden transitions, however, have increased in relative intensity with respect to the 2018 observations, especially the λ3869 of the [Ne III](1) doublet that is among the strongest lines in the spectrum. The He II λ4686 emission line is also one of the strongest lines (see Fig 12). The [O III] lines are present but weak. We also identify numerous weaker emissions from He I (triplet and singlet) and highly ionized metals: [Fe VI] λ5177, 5147, 5236 and 5678; [Fe VII]
Fig. 7. Evolution of the Si II doublet (RMT 2) transition (see text for details). Y axis units are erg/cm$^2$/s/$\AA$. The colored vertical lines are identical to those in the previous figures. The photometric state (min, max) of the spectra is indicated within each panel.

$\lambda$6086, 5276 and 5720; [Ca V] $\lambda$5309 and 6086 (blending with [Fe VII]). [Fe X] $\lambda$6373 may be weakly present in a blend with other emissions of difficult identification. [N II] $\lambda$5755 is present but weaker than He I $\lambda$5876 and [Fe VII] $\lambda$5720, while the fractional contribution of [N II] $\lambda$6584,5648 to H$\alpha$ is insignificant. Other forbidden transitions are from [Ar III] $\lambda$7136, 7751, [Ar IV] $\lambda$7169 and [Ar V] $\lambda$7006. There are a few lines which we are unable to identify, in particular, $\lambda$6638 and 6487, although are well isolated and not in a blend. We detect no C II or C III transitions and only very weak C IV $\lambda$5801,5812.

The two FIES spectra confirm that 17hx entered an optically thin stage since the line profiles remain unchanged in the two epochs (see Fig. 13). The ejecta however are not yet in nebular conditions how we will show in Section 6.2.

6.1. Central source spectral energy distribution constraints

We can infer a few important things from the comparison of the 2019 FIES spectra with those from 2018, and the intercomparison of the FIES spectra. The strengthening of the He II emission together with the appearance of the coronal lines in the later spectra indicates that the ionization degree has increased and that the ejecta is exposed to EUV/x-ray photons. The strengthening of the [O III] emission lines, instead, indicates that the density has decreased. The LISA and HEROS observations demonstrate that in 2018 the density of the expanding gas was still too high to display a significant increase in ionization and that the ejecta was barely beginning to “thin”. Conversely, in 2019 the density of the ejecta must have decreased enough to become substantially ionized.

Although we cannot compare the relative intensities at the two 2019 epochs along the whole wavelength range of the FIES spectra because of the scattered light contamination (May spectrum) and color losses (July and possibly May spectra), we can compare them where their continuum matches, i.e. in the range 4600-5200 $\AA$. This is sufficient to establish that the He II line ($\lambda$4686) intensity remained constant or slightly increased, that [O III] $\lambda$5007 slightly decreased and more so H$\beta$, while [Fe VII] $\lambda$$\lambda$5147,5177 and [Fe VII] $\lambda$4942 remained constant.

Fig. 8. Evolution of the O I triplets (RMT 1, top, and 4, bottom). Note that triplet (1) is resolved in the narrow absorption at $\sim$460 km/s. Together with the triplet (1) we overplot (gray line) the H$\delta$ profile for a comparison (see text for details; note that the H line has been arbitrarily offset in each subpanel; in the bottom subpanel it has also been scaled by a factor 0.5). Note that the blue line of the Ca II triplet is included in the bottom panel and that it shows similar behavior to the O I RMT 4. The Y axes units are erg/cm$^2$/s/$\AA$. The colored vertical dotted lines have the usual meaning. The photometric state (min, max) of each spectrum is indicated in each subpanel.
Weakening of the hydrogen emission together with the constancy of the He II and coronal lines, requires that the ionizing source is still active.

The coronal lines emission profiles are at least as broad as the permitted and the nebular transitions. They also display the same structures and their profiles are unchanged between the two epochs (Fig. 13). This precludes the role of shocks in their formation. Shocks excitation of different regions of the ejecta, or between the ejecta and any circumstellar material, should be localized at the colliding region and therefore display marked differences between coronal and permitted or nebular line profiles. They should also produce changing profile with time as the shock propagates. That said, we can constrain the incident spectral distribution of the ionizing source using the coronal lines and transitions from elements that present a range of ionization, e.g. in addition to [Fe VII], [Fe VIII] and possibly [Fe X], He I and He II \(^4\). The corresponding ionization potential (IP) are in the range 75 to 230 eV for iron, and 24 to 54 eV for helium. Since [Fe X] is very weak and since we certainly do not detect [Fe XIV] or [Fe XII], we place the upper cut-off of the ionizing source in the range 200-250 eV (the IP for Fe\(^{10+}\) is \(\sim\)260 eV).

\(^4\) The relative intensity of the [Ar III] to [Ar V] transitions cannot be compared because they lay in the region of scattered light.

The stronger [Fe VII] and [Fe VI] transitions compared to the (putative) [Fe X] (which has a transition probability \(\sim\)100 times greater) requires substantial flux from the ionizing source in the range 75-100 eV. It cannot be much below that otherwise He\(^+\) would be over-ionized (although the fraction of doubly ionized helium is increasing). On the low energy side, we place the low cutoff at about 20 eV in order to have H just recombining (it weakens between May and July because of expansion) and He ionizing.

6.2. Ejecta mass and filling factor

The invariant structures in the line profile (both forbidden, i.e. optically thin transitions by definition, and in the Balmer lines) indicate that the gas is in free expansion and optically thin. The observed decrease of the H\(\beta\) emission (-15-20%) in consistent, within the errors, with the density dropping with time, \(t\) as \(t^{-3}\) (-20-25%) typical of freely expanding gas in ballistic motion and of CNe. Hence, we can constrain the electron density from the [O III] lines as we have done for late nebular spectra of CNe (e.g. Shore et al. 2013a, 2013b; Shore et al. 2016; Mason et al. 2018). We are aware, however, that the relative intensity of the [O III] components in 17hx indicates that collisional de-excitation is not...
Fig. 10. The evolution across four min-max cycles of the H, He I and Fe II lines, representing respectively intermediate, high and low ionization potential energy atoms. The exact photometric state of each spectrum is indicated in the first column panels; the age (in days) is on the left. Note that the He I transition is contaminated by Na I D both of interstellar and ejecta origin. The Na I D transition (emission and absorption) originating in the ejecta is particularly evident in the spectra taken between day 82 and 101.
negligible and the density must exceed the critical density. We verified that for spectra of CNe whose [O III] emission had similar relative strength to 17hx, the derived ejecta mass is smaller than that computed from later spectra because of the collisional damping of the diagnostic lines. We therefore used the [O III] diagnostic to estimate the nebular density and constrain the ejecta mass, being aware that the first is likely underestimated because of the wavelength dependent flux losses (see Section 2) and the latter will be underestimated because of collisional damping of the forbidden transitions. Fig. 14 shows the nebular density derived using the [O III] diagnostic for an assumed electron temperature of $T_e \sim 10000$ K (Osterbrock 1989, chapter 5), velocity bin per velocity bin. Since the 4959 Å component is heavily blended with [Fe VII] we disentangled its contribution using the 5007 Å profile scaled by the ratio of their transition probability (2.9 in NIST). We find an average density of $\sim 3.5-4 \times 10^{-3}$ cm$^{-3}$ with some minor fluctuation across most of the line width.

We constrained the ejecta’s geometry by mimicking the emission line profiles with our bicone code, i.e. a Monte Carlo simulation that scatters, in ballistic but otherwise random distribution, 10-30 thousand points (representing, each, individual ejecta structures) within a biconical geometry that can vary in opening angle, thickness and orientation (Shore et al. 2013; Mason et al. 2018). The closest matching model has maximum velocity $v_{\text{max}} = 1500$ km/s, high inclination ($\sim 80$ deg), wide opening angle ($\sim 140$ deg) and is geometrically thin compared to other novae (i.e. $v_{\text{max}} \sim 50$ to 60% of $v_{\text{max}}$ compared to $\sim 30\%$ for nova Mon 2012, nova Del 2013 and nova Cen 2013, see Shore et al. 2013a, 2016, and Mason et al. 2018, respectively). With the density, its radial gradient and the geometry of the ejecta we can derive the ejecta mass upper limit for a filling factor of unity: $M_{\text{ej}} \sim 9 \times 10^{-3}$ $M_\odot$. We emphasize that, although this estimate is model dependent, requiring the departure from sphericity, it is independent of distance. We know, however, that the filling factor, $\varepsilon$, is < 1 since the structures in the line profiles indicate fragmented ejecta. The question is whether $\varepsilon$ can reduce the ejecta mass to the range of normal CNe. To obtain $\varepsilon$ we need the absolute luminosity of a purely recombination line, H$\beta$, sampling the same volume as the nebular diagnostic. This requires knowing the distance. The observed line of sight H I 21 cm emission is optically thin and its matching profile with the atomic interstellar absorption lines (see Fig. 1) indicates that 17hx is fairly distant. Using the Galactic rotation curve, for the highest observed radial velocity of both the 21 cm emission and Na I and Ca II absorptions, $v_{\text{LSR}} \approx 120$ km/s, we obtain a line of sight dis-
7. Discussion and conclusions

ASASSN-17hx resembles a CN in some properties, but it is strikingly anomalous relative to the majority of CNe in a number of other aspects. Specifically, 17hx can be explained with the same dynamical and bolometric physical model we have advocated for CNe (Shore et al. 2012, 2013a, 2016, de Gennaro Aquino et al. 2014, Mason et al. 2018) that does not require a wind, or dynamically interacting multiple ejections. The light curve results from redistribution and reprocessing of the photons emitted from a central source as they pass through the ballistically expanding ejecta. The ejecta are structured as in CNe. The spectra developed, analogously to all CNe, from an initial opaque phase, through a transition/semi-opaque phase, to a transparent nebular one. The oddities are in the details.

The early outburst was dominated by large oscillations that for amplitude and interval between peaks are unusual for CNe. The nebular spectra displayed unusual line strength in the coronal emissions. The estimated ejecta mass is higher or much higher than typical CNe and this, combined with the observed velocity, implies a larger kinetic energy than typical CNe. We now discuss each of these points in detail.

7.1. On the light curve oscillations

Our early spectroscopy demonstrates that 17hx optically thick phase oscillations were accompanied by changes in the degree of ionization of the expanding gas, with higher ionization observed at the minima than at maxima. Thus, the photometric and

tance of \( \approx 7.6 \) kpc. Moreover, the total reddening inferred from infrared maps in 17hx direction is E(B-V) = 1.5 mag (Schlafly & Finkbeiner 2011) and is about twice our derived value (see Section 2.1). Considering that most of the dust is confined within the Solar circle, our derived E(B-V) is consistent with 17hx being located at about the same distance as the Galactic center. We therefore take 7.6 and 8.5 kpc as a lower and upper limits for the distance to constrain \( \varepsilon \). The dereddened H\( \beta \) integrated flux is \( L(H\beta)^{\text{obs}} = 2.04 \times 10^{-11} \) erg/cm\(^2\)/s/\( \AA \) (=1.95\times10^{-12} \) in the original extinct spectrum). As in our previous studies, we define \( \varepsilon \equiv L(H\beta)^{\text{obs}}/L(H\beta)^{\text{predicted}} \) where the prediction is based on our computed \( n_e \) and volume from the models, assuming case B recombination. The latter may overestimate the real recombination rate, given the high densities of the ejecta. For the distance bounds, we obtain 0.08 \( \leq \varepsilon \leq 0.1 \), yielding ejecta mass in the range \( 7 \times 10^{-4} \leq M_e \leq 9 \times 10^{-4} M_\odot \). These estimates are at least an order of magnitude higher than the largest values derived for CNe, especially those we have similarly analyzed.
spectroscopic changes can result from alternating ionization and recombination waves propagating through the expanding gas as the underlying source varied in brightness and SED (or hardness). When the incident flux is higher or harder, the pseudo-photosphere recedes, the continuum peaks at shorter wavelength the visible and the NIR fluxes drop, the iron peak elements ionize and He I is excited. This is a photometric minimum. If the incoming radiation is softer, the pseudo-photosphere expands, the brightness of the continuum at long wavelength increases and the spectrum returns to its previous state of lower excitation and ionization degree in the emission line spectra. These might appear very slow when the density (i.e. \( \tau \)) is high, since the diffusion timescale is longer, but will become more frequent as the density (and therefore \( \tau \)) drops. The amplitude of the oscillations decreases with time since larger portions of the ejecta become transparent because of the expansion. This can explain both the 17hx light curve and the "O" (oscillation) and "J" (jittering) type light curves shown in Strope et al. (2010).

This brings us to the question of the nature of the central source. The pulses from the underlying source must be sufficiently intense and rare to produce the observed effect on the ejecta. Smaller amplitudes and more closely spaced peaks like those observed in, e.g., DQ Her or nova Sgr 2015b, would require higher pulse frequencies and lower amplitudes. The light curve jitters or oscillations could appear already at maximum or during early decline, depending on the initial ejecta opacity and the pulse cadence of the underneath source. Conversely, the smoothly declining light curves would either have no pulses in the underlying source or a very rapidly expanding ejecta or a combination of the two. In any case, given the variety of observed jitters and oscillations the pulses should be similar to non-Gaussian noise with an occasional stronger signal capable of producing significant/outstanding variations in the light curve. These pulses are not the oscillations observed in the x-ray count rate at the "onset" of the supersoft source phase: those are likely too rapid, too small and, most importantly, explained by the differential changes in the transparency of individual intervening ejecta structures. The non-Gaussian noise-like pulses could re-

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**Fig. 13.** Comparison of the coronal, permitted and nebular line profiles in the July 2019 FIES spectrum. The profiles share structures and width (see text for more details). We plot in grey the same profiles in the May 2019 FIES spectrum, showing invariance of the line profile evolution. Y-axes are flux in erg/cm\(^2\)/s/Å.

**Fig. 14.** The [O III] emission lines (July 2019 FIES spectrum) and the corresponding electron density in velocity space. The [O III] is in blue solid color and the [O III] is in green dotted color. Their units in erg/s/cm\(^2\)/Å, is indicated in blue on the right axis. The black solid line is the corresponding electron density, \( n_e \), per resolution element (units in cm\(^{-3}\) on the left axis). The \( n_e \) is plot only within the velocity range [-600,+600] km/s, since beyond it, the noise dominates.
result from the white dwarf (WD), or the resumption of accretion, or any temporary unstable interaction that might be occurring in the post-outburst phase on timescales of days to weeks. We suggest that those pulses, especially when they appear at maximum, could be due to unstable burning by a nuclear source igniting just at the critical temperature. This depends on the mass of the WD. Massive WDs reach higher temperatures while mixing occurs on a relatively small envelope. Instead, low mass WDs reach lower temperatures closer to the critical value for the TNR ignitions so that, because of mixing, we can imagine a situation of marginal stability and intermittent burning. The envelope mass is larger and mixing take longer and is less uniform. The burning layer would be embedded below a substantial envelope which would be partially radiative in its outer part, making the convection zone deeper and the supersoft source appear softer. The lower the WD mass, the more extreme this could be. The reduced degeneracy of the envelope would make it similar to unstable shell burning (Schwarzschild and Harm 1965; see also José 2016, Iliadis 2007). Supporting this picture, the ionization degree displayed by the FIES spectra suggests a ionizing source that is energetically limited to the range 20-250 eV and peaking between 75-100 or 75-150 eV. While we do not know its SED, it was not a SSS in its usual sense. Otherwise, more highly ionized Fe would have been detected. The inferred energy distribution is consistent with a buried nuclear source, or a cooling WD, or an accretion disk.

7.2. On the late spectral appearance and the coronal lines

17hx is also peculiar for the relative strength of its coronal lines. When compared to classical nova followed until their “coronal phase” as in the CTIO survey by Williams et al. (1991 and 1994), we note the following. First, CNe that display strong [Ne V] lines, while for 17hx we lack such information as our spectra are not sufficient. Second, the lines of [Fe VII] or higher transitions are always weak compared to both nebular and permitted transitions, usually ≤0.2I(Hβ). Examples in the CTIO survey are nova Sco 1989b, nova Set 1989, nova Cen 1991, nova Oph 1991a, nova LMC 1991, nova Sgr 1991 and nova Pup 1991 (Williams et al. 1991, 1994), and nova Aql 1999b (Iijima and Enosoglu 2003). The only objects that are similar to 17hx are nova Oph 1988 (V2214 Oph) in the CTIO survey, and V723 Cas, that was monitored by Iijima (2006) over 6 years. Both objects, like 17hx, developed strong coronal lines and weak [O III]. They also displayed strong [Ne V] lines, while for 17hx we lack such information as our spectra are not sufficiently extended in the blue. Both V2214 Oph and V723 Cas were slow novae with extreme oscillations during the early decline (whatever “early” might mean in this case). Strope et al. (2010) classified the first as an S-type nova (i.e. smooth light curve), but they missed early decline data points which are published in Williams et al. (2003, although these lack error bar). V723 Cas, whose light curve Strope et al. (2010) assigned to the J class, had a remarkably slow spectroscopic evolution (Iijima 2006) that is very similar to 17hx. It took about 18 months to enter the optically thin phase. Two years after outburst it showed substantial spectroscopic evolution with dramatic strengthening of the He II line λ4686 and the appearance

5 For example, for Swift XRT spectra, the hardness ratio is usually estimated in the interval 0.2-1.0 keV, while our upper cutoff is at the lowest energy end of this band.

6 For the obvious reasons of the interaction between the ejecta with the donor’s wind, symbiotic novae are excluded from this comparison.

7.3. On the ejecta mass

To continue the comparison of 17hx and V723 Cas we look at their ejecta masses. Iijima (2006) using integrated line fluxes derived an unusually large ne, but a quite small mass (5×10⁻⁶ M⊙), possibly incompatible with the observed slow evolution. The line fluxes reported in Iijima’s Table 7 indicate a strongly collisionally damped [O III] ratio 4 years after outburst. We derived an independent value for the V723 Cas ejecta parameters, estimating the [O III] and Hβ lines intensity from Iijima’s Figure 14 and modeling their profiles with our Monte Carlo simulation and maximum expansion velocity vₘₐₓ=1600 km/s. The upper limit for the mass, for a filling factor of unity, is 0.03 M⊙. Adopting Schaefer’s (2018) distance of 5.6±1.2 kpc we derive e=0.01 and M_ej=3×10⁻⁴ M⊙ for V723 Cas. Although uncertain these values are similar to those derived for 17hx. The two objects have a somewhat large ejecta mass, about an order of magnitude larger than typical CNe, and possibly more. The largest uncertainty is in the distance and, the closer the object, the more CNe-like the ejecta mass, but the smaller the filling factor which falls in the range for recurrent novae (e.g. T Pyx, Shore et al. 2013b). It is interesting to note that these large ejecta masses expand with velocities that are comparable to those of typical CNe, implying larger kinetic energy.

In their nova sequences, Yaron et al. (2005) found an increase in the ejected mass with decreasing white dwarf mass, with a 0.4 M⊙ WD ejecting < 7×10⁻⁴ M⊙. This is at the lower limit of our range for the ejecta mass in 17hx. Furthermore, since these were one dimensional simulations, the filling factor is unity by definition. Hence, the mass and kinetic energies we derive are likely far higher than these models produced. The same holds for the TNR results from Starrfield et al. (2013), who found that even for low mass accretion rates and low mass WDs there is a TNR that can ultimately eject some mass, although neither as much as in Yaron et al. (2005) nor near our estimated value for 17hx. Starrfield et al. (2013) also remark that unsteady nuclear burning would result for accretion of solar composition material and no mixing.

7.4. On the progenitor

Saito (2017) identified the 17hx progenitor with a Ks~16.7 mag star in the VVVX survey, also matching a nearby Gaia DR2 source of G=19.3 mag. The latter, once dereddened and scaled to 7.6 kpc (see also Evans et al. 2018), has an absolute magnitude M_V ~3 mag, consistent with old nova absolute magnitudes determined by Selvelli and Glimozzi (2019). The same exercise repeated in K band produce M_K=2 mag which is somewhat bright for a cool main sequence companion, but compatible with an evolved donor. Saito’s identification implies that 17hx outburst amplitude was 11 mag. We note that there are not other visible...
objects nearby 17hx and that its outburst amplitude would be much larger than 11 mag should the identification not be con-

In conclusion, after this long presentation and physical dis-

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References

Berardi, P., Sims, W., & Sollecchia, U. 2017, ATEL 10558
Bohlin, R.C., Savage, B.D., & Drake, J.F., 1978, ApJ, 224, 132
Cao, Y., Kashiwai, M.M., Neill, J.D., et al., 2012, ApJ, 752, 133
De Gennaro Aquino, I., Shore, S.N., Schwarz, G., et al., 2014, A&A, 562, 28
Dekker, H., D’Odorico, S., & Kauter, A., 2000, SPIE, 4008, 534
Duerbeck, H.W., 1981, PASP, 93, 165
Evans, D.W., Rieke, M., De Angeli, F., et al., 2018, A&A, 616, A4
Frandsen, S., & Lindberg, B., 1999, Anot. Conf, 71
Guarro, J., Berardi, P., Sollecchia, U., 2017, ATEL 10737
Iildias, C., 2007, Nuclear Physics of Stars, Published by Wiley-VCH Verlag, Weinheim, Germany
Iijima, T., & Esenoglu, H.H., 2003, A&A, 404, 997
Iijima, T., 2006, A&A, 451, 563
José, J., 2016, Stellar explosions - hydrodynamics and nucleosynthesis, CRC Press - Taylor and Francis group, Boca Raton, Florida, USA
Kafka, S., 2019, Observations from the AAVSO International Database, https://www.aavso.org
Kalberla, P.M.W., Burton, W. B., & Hartmann, D., et al., 2005, A&A, 440, 775
Keenan, P.C., & Hynck, J.A., 1950, ApJ, 111, 1
Kira, N.P.M., Page, K.L., Williams, S.C., et al., 2017, ATEL 10636
Kurtenkov, A.T., Tomov, T. & Pessev, P., 2017a, ATEL 10527
Kurtenkov, A.T., Napetova, M. & Tomov, T., 2017b, ATEL 10725
McLaughlin, D.B., 1943, Publ. Obs. Univ. of Michigan, S. 149
Mason, E., Shore, S.N., De Gennaro Aquino, I., et al., 2018, ApJ, 853, 27
Munari, U., & Zwieten, T., 1997, A&A, 318, 269
Munari, U., Oehner, P., Hambusch, F.J., et al., 2017a, ATEL 10572
Munari, U., Traven, G., Hambusch, F.-J., et al., 2017b, ATEL 10641
Munari, U., Hambusch, F.-J., Frigo, A., et al., 2017c, ATEL 10736
Payne-Gaposchkin, C., 1957, The galactic novae, North Holland Publishing Company, Amsterdam, Netherlands
Pavana, M., Anupama, G.C., Selvakumar, G. & Kiran, B.S., 2017, ATEL 10613
Saito, R.K., Hempel, M., & Minniti, D., 2017, ATEL 10552
Schaefer, B.E., 2018, MNRAS, 481, 3033
Schlafly, E.F., & Finkbeiner, D.P, 2011, ApJ, 737, 103
Schwarz, G.J., Ness, J-U., Osborne, J.P., et al., 2011, ApJS, 197, 31
Schwarzschild, M., & Harm, R., 1965, ApJ, 142, 855
Selvelli, P., & Gilmozzi, R., 2019, A&A, 622, 186
Shore, S.N., Sonneborn, G., Starrfield, S., Gonzalez-Riestra, R., & Polidan, R.S., 1994, ApJ, 421, 344
Shore, S.N., Augusteijn, T., Ederoclite, A., & Ubas, H., 2012, A&A, 537, 2
Shore, S.N., De Gennaro Aquino, I., Schwarz, G.J., et al., 2013, A&A, 553, 123
Shore, S.N., Schwarz, G.J., De Gennaro Aquino, I., et al., 2013b, A&A, 549, 140
Shore, S.N., Mason, E., Schwarz, G.J., et al., 2016, A&A, 590, 123
Shore, S.N., Kunit, N.P., Mason, E., De Gennaro Aquino, I. 2018, A&A, 619, 104
Staneck, K.Z., Kochanek, C.S., Chornock, L., et al., 2019, ATEL 10523
Startzfeld, S., Timmes, FX., Hix, W.R., et al., 2013, IAUS Binary Paths to Type Ia Supernovae Explosions, 281, 166
Strope, R.J., Schaefer, B.E., & Henden, A.A., 2010, ApJ, 140, 34
Telting, J.H., Avila, G., Buchhave, L., et al., 2014, Astronomische Nachrichten, 335, 41
William, R.E., Hamuy, M., Phillips, M.M., et al., 1991, ApJ, 376, 721
Williams, R.E., Phillips, M.M., & Hamuy, M., 1994, ApJS, 90, 297
Williams, R.E., Hamuy, M., Phillips, M.M., et al., 2003, JAD, volume 9
Williams, S.C., Darnley, M.J., 2017, ATEL 10542
Yaron, O., Prialnik, D., Shara, M.M., & Kovetz, A., 2005, ApJ, 623, 410