

The Changing-look Optical Wind of the Flaring X-ray Transient Swift J1858.6-0814

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ABSTRACT

We present the discovery of an optical accretion disk wind in the X-ray transient Swift J1858.6-0814. Our 90-spectrum data set, taken with the 10.4m GTC telescope over 8 different epochs and across five months, reveals the presence of conspicuous P-Cyg profiles in He I at 5876 Å and H α . These features are detected throughout the entire campaign, albeit their intensity and main observational properties are observed to vary on time-scales as short as five minutes. In particular, we observe significant variations in the wind velocity, between a few hundreds and ~ 2400 km s⁻¹. In agreement with previous reports, our observations are characterised by the presence of frequent flares, although the relation between the continuum flux variability and the presence/absence of wind features is not evident. The reported high activity of the system at radio waves indicates that the optical wind of Swift J1858.6-0814 is contemporaneous with the radio-jet, as is the case for the handful of X-ray binary transients that have shown so far optical P-Cyg profiles. Finally, we compare our results with those of other sources showing optical accretion disk winds, with emphasis on V404 Cyg and V4641 Sgr, since they also display strong and variable optical wind features as well as similar flaring behaviour.

Keywords: accretion, accretion discs X-rays: binaries stars: black holes stars: winds, outflows

1. INTRODUCTION

In addition to a large variety of accretion-related observables, mostly seen in X-rays (McClintock & Remillard 2006; van der Klis 2006; Belloni et al. 2011), low-mass X-ray binaries (LMXBs) also show a complex outflow phenomenology. This initially included synchrotron radio emission from jets, either in the form of compact sources or discrete ejections (e.g. Mirabel & Rodríguez

1999, Fender et al. 2004), and subsequently X-ray winds of highly ionized material (e.g. Miller et al. 2006, Ponti et al. 2012, Díaz Trigo & Boirin 2016). These outflows can be the dominant source of power released and mass consumed/expelled by the system during some accretion phases (Fender & Muñoz-Darias 2016), and as such represent a fundamental part of the entire accretion process onto stellar-mass black holes (BHs) and neutron stars (NSs).

Furthermore, intense and sensitive spectroscopic campaigns carried out over the last few years have unveiled the presence of optical winds in several BH

Table 1. Observing log. All the data were taken in 2019.

Epoch	Observing window (UT)	Grism [†] and exposures	g-band magnitude
1	24/03 (05:14–05:49)	LR (7 × 280 s)	16.1
2	14/04 (05:30–06:16)	LR (9 × 280 s)	15.4–15.7
3	30/04 (04:32–05:22)	LR (10 × 280 s)	15.9–16.2
4	12/05 (03:36–04:32)	LR (1 × 280 s) + HR (10 × 280 s)	15.7–16.4
5	09/06 (03:52–04:48)	LR (1 × 280 s) + HR (10 × 280 s)	16.2–16.5
6	01/07 (04:03–04:59)	LR (1 × 280 s) + HR (10 × 280 s)	16.2–16.4
7	06/08 (00:00–01:52))	HR (21 × 280 s) + LR (1 × 280 s)	16.3
8	18/08 (21:57–22:43)	HR (9 × 284 s)	15.7–16.4

[†]LR and HR indicate Lower ($\sim 350 \text{ km s}^{-1}$) and Higher ($\sim 160 \text{ km s}^{-1}$) Resolution grism (R1000B and R2500R, respectively)

transients. P-Cyg profiles have been discovered in V404 Cyg (Muñoz-Darias et al. 2016; Muñoz-Darias et al. 2017; Mata Sánchez et al. 2018; see also Casares et al. 1991 for detections during the 1989 outburst) and MAXI J1820+070 (Muñoz-Darias et al. 2019b), while an archival search showed the presence of conspicuous wind signatures in several outbursts of V4641 Sgr (Muñoz-Darias et al. 2018; see Lindstrøm et al. 2005 and Chaty et al. 2003 for earlier reports). In addition, the classical systems GRO J1655-40 and GX 339-4 showed complex emission line profiles (Soria et al. 2000; Rahoui et al. 2014, respectively), while the intriguing optical dips of Swift J1357.2-0933 (Corral-Santana et al. 2013) have recently been found to be related to disk outflows seen at high orbital inclination (Jiménez-Ibarra et al. 2019a; Charles et al. 2019). All the above, together with the near-infrared P-Cyg profiles witnessed in at least one luminous NS system (GX 13+1; Bandyopadhyay et al. 1999; see also Homan et al. 2016), indicate that cold accretion disk winds (i.e. those detected at optical and infrared wavelengths) are a relatively common feature – perhaps ubiquitous – in the LMXB accretion phenomena. For the best studied case of V404 Cyg, these are found to have a severe impact on the accretion process and outburst evolution, with an associated mass outflow rate greatly exceeding the accretion rate, albeit this system might represent an extreme case (Muñoz-Darias et al. 2016; Casares et al. 2019).

Swift J1858.6-0814 was discovered by the BAT monitor on-board the Neil Gehrels Swift Observatory (Gehrels et al. 2004) on Oct 25, 2018, and soon after catalogued as a new galactic X-ray binary transient (Krimm et al. 2018). Since the early phase of the outburst, it became a target of special interest owing to its remarkable flaring behaviour at both X-rays (Ludlam et al. 2018) and optical wavelengths (Vasilopoulos et al. 2018; Baglio et al. 2018; Paice et al. 2018). This triggered the comparison with the BH transients V404 Cyg and V4641 Sgr by Ludlam et al. (2018), which was

reinforced by telegrams reporting the presence of intrinsic X-ray absorption (Reynolds et al. 2018) and optical winds (Muñoz-Darias et al. 2019a). In this letter, we present multi-epoch, high-cadence optical spectroscopic observations of Swift J1858.6-0814 showing that this system displays optical features indicating the presence of an accretion disk wind.

2. OBSERVATIONS AND DATA REDUCTION

We obtained optical spectroscopy using OSIRIS (Cepa et al. 2000) attached to the Gran Telescopio Canarias (GTC) at the Observatorio del Roque de los Muchachos in La Palma, Spain. The target was observed in eight different epochs over a time lapse of five months within March-August 2019. We obtained between 7 and 22 individual spectra per epoch with the grisms R1000B (4200 – 7400 Å) and R2500R (5575 – 7685 Å) depending on the night (see Table 1). This resulted in a total of 90 spectra with a time cadence of \sim five minutes and a velocity resolution of ~ 350 or $\sim 160 \text{ km s}^{-1}$ depending on the grism (measured from the FWHM of sky lines; i.e. assuming that resolution is dominated by the 1.0 arcsec slit and not the seeing). Weather conditions were good throughout the campaign, with seeing around ~ 1 arcsec and clear skies. Only epoch-1 was observed on a bright night at high airmass (~ 1.7) due to the very limited visibility window of the target at that time of the year. Across the entire campaign the slit was rotated so to include a brighter field star placed ~ 10 arcsec South-West from the target. In order to carry out a relative flux calibration, spectra from this object were treated in the same way as those of Swift J1858.6-0814. Data were reduced, extracted and wavelength calibrated using IRAF tools, while MOLLY and custom PYTHON routines were used for the analysis. From our g-band acquisition images (typically three per epoch and taken before the spectra) we derive magnitudes in the range 15.4–16.5 across the entire campaign (calibrated against Pan-STARRS).

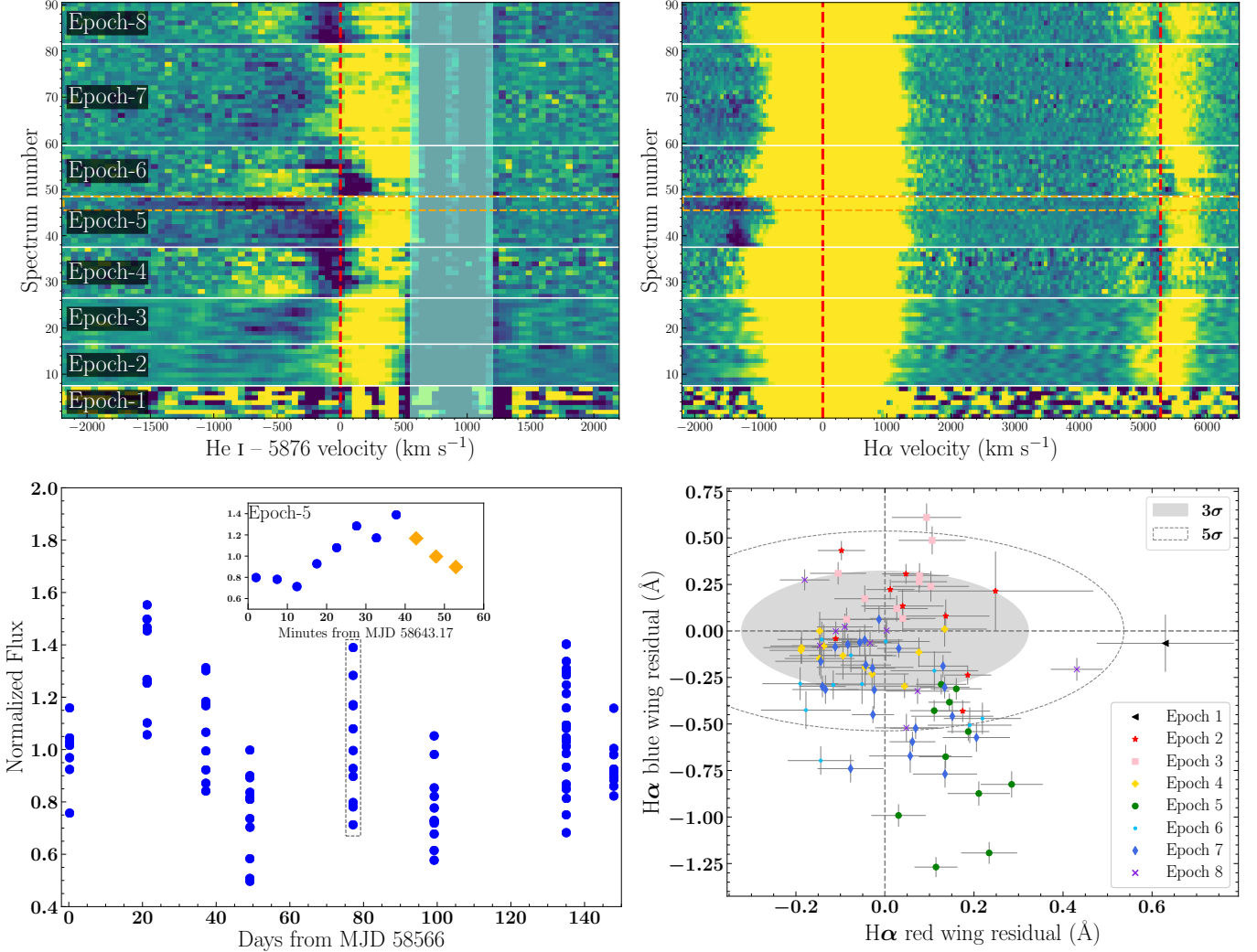


Figure 1. Evolution of selected emission lines and the continuum flux across the entire campaign. *Top panels:* trailed spectra for the He I-5876 (left) and H α (+He I-6678; right) spectral regions in velocity scale. Intensity is indicated by a color scale covering from 0.92 (deep blue) to 1.08 (bright yellow) times the continuum level, which was previously normalized. The masked region, containing the Na interstellar doublet in the red wing of He I-5876, is indicated by a green vertical stripe. *Bottom-left panel:* evolution of the continuum flux (6000–6250 Å) throughout the campaign. Data are represented normalized to the mean value. A zoom-in of epoch-5 (dashed-lined rectangle) is overlotted as an inset, with the orange diamonds corresponding to the spectra with the more conspicuous P-Cyg detections (dashed-lined, orange rectangles in the top panels). *Bottom-right panel:* H α excesses diagram for every spectrum with the exception of epoch-1, for which the epoch-averaged spectrum was used. The residuals are given in equivalent width (Å). The grey-shaded and dashed-lined circles indicate the 3σ and 5σ significance contours, respectively (see section 3.2).

3. RESULTS

We focus our analysis on the 5500–7200 Å spectral range covered by both the lower (R1000B) and higher resolution (R2500R) grisms. It includes the emission lines He I at 5876 Å (He I-5876), H α (6563 Å), He I-6678, as well as He I-7065. The R1000B spectra (epochs 1-7) also include the Bowen blend (mainly N III at 4641 Å) and He II at 4686 Å. These emission lines are detected across epochs 2 to 7, whilst the limited data quality of epoch-1 only allows to study H α in great detail.

Fig. 1 shows the trailed spectra (top panels) corresponding to He I-5876 (left) and H α (plus He I-6678; right). Intensity is indicated by a color scale covering from 0.92 (deep blue) to 1.08 (bright yellow) times the continuum level. Each spectral region was independently normalized by fitting the adjacent, local continuum with a first order polynomial. This was done by considering relatively broad continuum regions at each side of the emission lines ($\sim \pm 10000$ km s $^{-1}$), masking the lines themselves and their closest continuum, as well as other contaminant features (e.g. He I-6678 for H α).

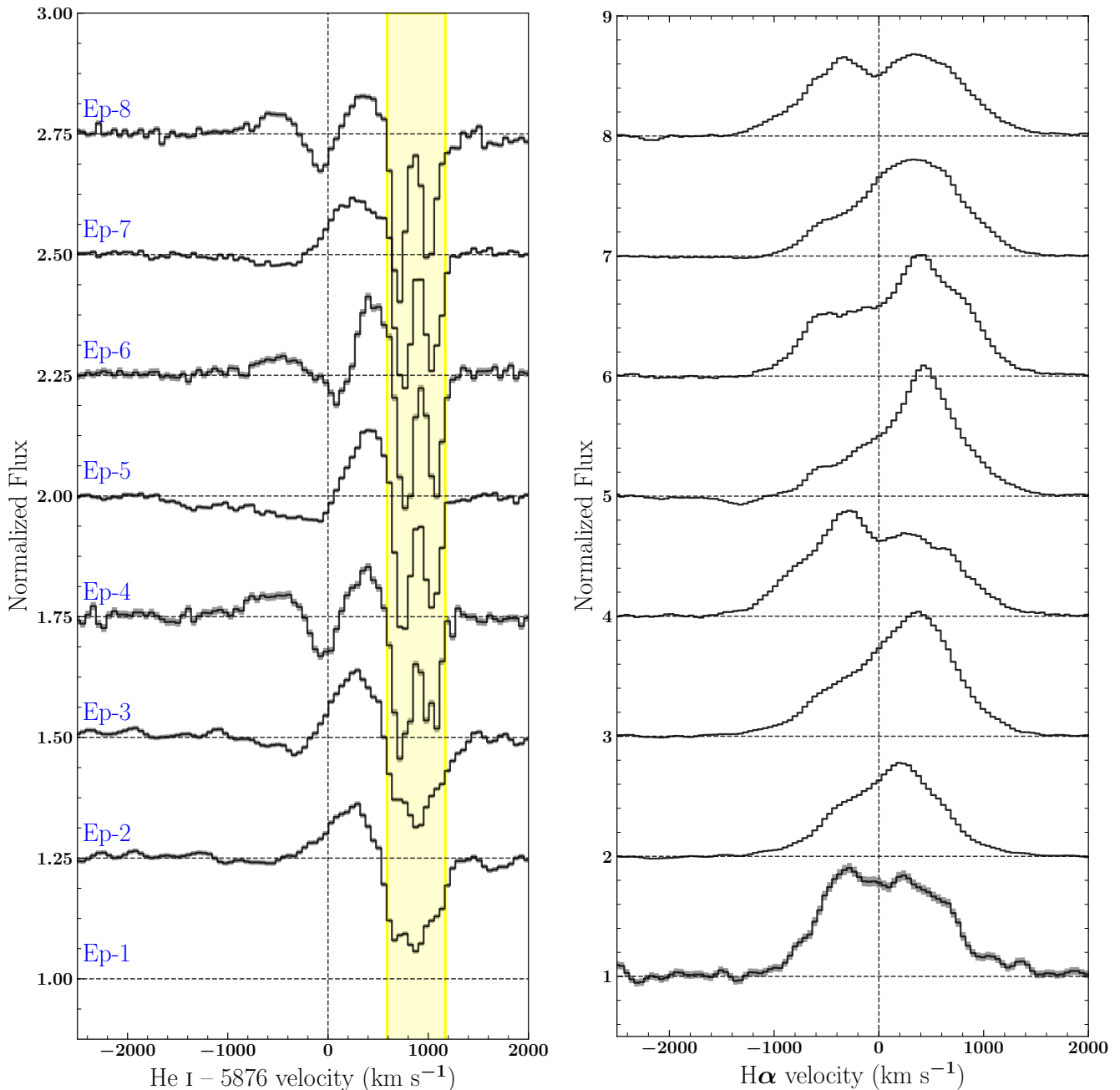


Figure 2. Evolution of the He I-5876 (left panel) and H α (right panel) emission line profiles using epoch-averaged, normalized spectra. Data are represented using offsets of 0.25 and 1, respectively. The epoch-1 spectrum of He I-5876 is not represented due to its poor quality. The yellow-shaded region indicates the spectral region contaminated by the Na doublet (interstellar).

By repeating this analysis with slightly different mask configurations we estimate that the normalization process introduces an uncertainty in the continuum level of ~ 0.3 percent (i.e. much lower than the ± 8 percent intensity scale used in the trailed spectra). The blue wing of the He I-5876 emission profile, typically the most sensitive to the presence of optical winds (e.g. Muñoz-Darias et al. 2016), show blue-shifted absorptions in vir-

tually every observing epoch. These absorptions (represented by deep blue traces) make the blue part of the line disappear completely during a large part of the observing campaign. We interpret this as the signature of an accretion disk wind, similar to those previously witnessed in some BH transients.

A closer look at the trailed spectra reveals that the blueshifted He I-5876 absorptions are more conspicuous

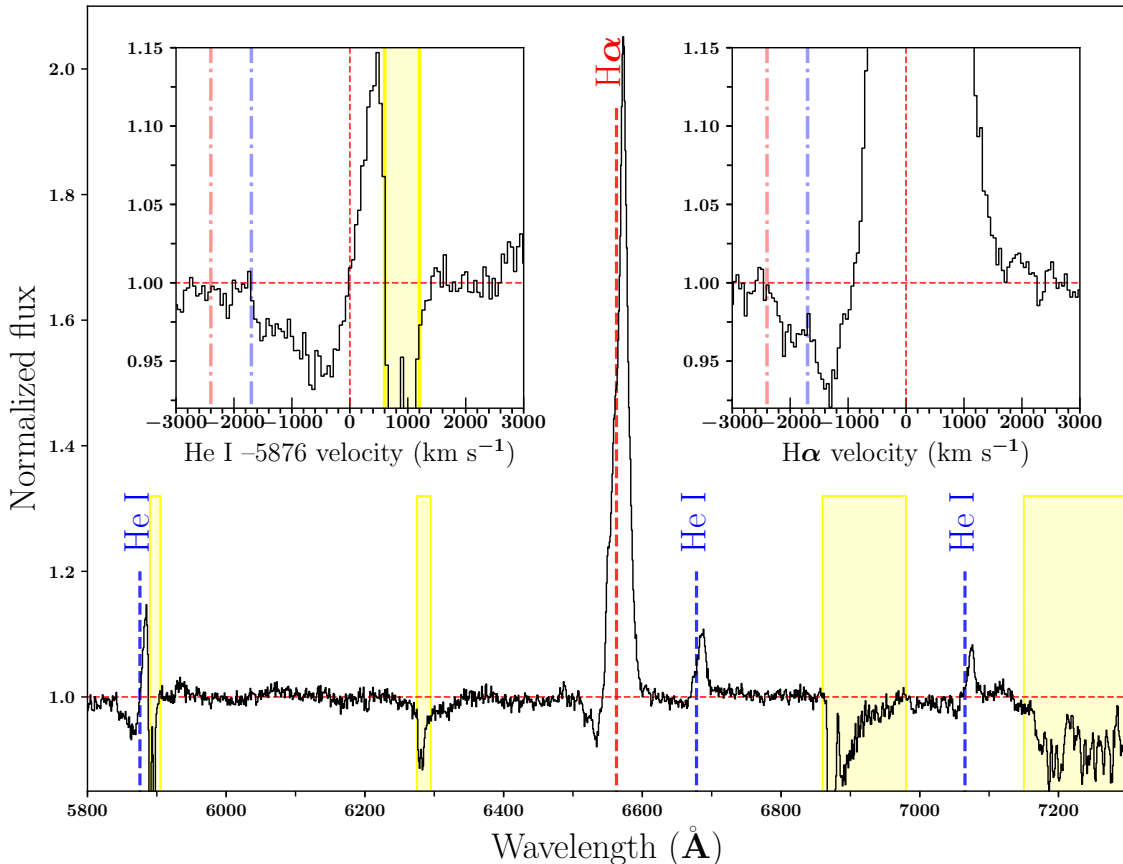


Figure 3. Average of the last 3 spectra obtained during epoch-5, when the deepest, high-velocity blue-shifted absorption features are present. The insets show a zoom-in of He I-5876 (left) and H α (right) in velocity scale, with the blue and red dashed-dotted lines indicating the corresponding blue-edge wind velocities of 1700 km s $^{-1}$ and 2400 km s $^{-1}$, respectively. The yellow-shaded regions indicate spectral regions contaminated by interstellar or telluric features.

between epochs 3 and 8, whilst H α shows them only on epoch-5 and more weakly on epoch-7 (Fig 1, top-right panel). Likewise, He I-6678 behaves in a consistent way with He I-5876, albeit it is significantly less intense than the latter, and therefore any observational feature is expected to be less marked.

Fig 2 (left panel) shows the evolution of He I-5876 using epoch-2 to -8 nightly average spectra. We can distinguish two groups of data by looking at the evolution of the blue wing of the emission profile (i.e. negative velocities). Epochs 3, 5 and 7 (and also 2 to some extent) show standard P-Cyg profile shapes (i.e. blue-shifted absorption and red-shifted emission), with the most conspicuous case (epoch-5) reaching a terminal velocity¹ of 1700 km s $^{-1}$ and an absorption depth at the core of the

profile of 95% the continuum level. An usual approach to determine the terminal velocity in a systematic way is to perform Gaussian fits to the blue-shifted absorption (e.g. Muñoz-Darias et al. 2016). However, in this case the shapes are clearly non-Gaussian and hence the velocity was simply determined by visual inspection. Given the high signal-to-noise ratio of our data, we estimate this to be accurate within ~ 100 km s $^{-1}$ (see e.g. insets in Fig. 3). The second group of data is formed by epochs 4, 6 and 8. They show odd profiles characterized by a strong and slightly blue-shifted absorption troughs reaching down to 92% the continuum level in some cases (epoch-4 and -8). However, the corresponding epoch-averaged H α lines are dominated by standard double-peaked profiles during these times (Fig 2; right panel). The combination of a wind-induced blue-shifted absorption at low velocity, together with an underlying double-peaked profile (observed in H α) offers a viable explanation for the behaviour of He I-5876 during these epochs. Under this interpretation, the emission bumps at ~ -500 km s $^{-1}$ would be associated with a partial

¹ Throughout the paper, the terminal velocity of the wind is identified as that of the blue-edge of the P-Cyg absorption component. However, we note that this assumption is not always straightforward and is expected to depend on e.g. the physical properties of the ejecta

absorption (by the wind) of the double-peaked disk component. If this is the case, the blue peak would appear weaker than the red one even when $H\alpha$ shows the opposite behaviour (e.g. epoch-4). This dimming of the blue emission suggests that even though the blue edge of the absorption indicates wind velocities of just a few hundreds km s^{-1} , a higher velocity component is likely present.

It is important to remark that while the $H\alpha$ profile seems to be unaffected during these low-velocity wind phases, it is clearly asymmetric or even show blue-shifted absorptions during the remaining epochs. As can be seen in the trailed spectra (Fig. 1), the most clear $H\alpha$ wind detection also occurs on epoch-5. The wind signature is particularly strong in the last three individual spectra of this window (indicated by a dashed-lined, orange rectangle in the trailed spectra), whose averaged spectrum is shown in Fig. 3. Profound P-Cyg profiles are detected in He I-5876, and especially $H\alpha$ with a blue-shifted absorption reaching 90% the continuum level and a blue-edge velocity of $\sim 2400 \text{ km s}^{-1}$. This is larger than $\sim 1700 \text{ km s}^{-1}$ observed in He I-5876 (see insets in Fig. 3).

3.1. Continuum flux variability

Given the strong variability observed in the line spectral profiles, we decided to study the evolution of the continuum flux. This was done by dividing each target spectrum by that of the field star included in the slit and subsequently integrating the flux from 6000 to 6250 Å. The bottom-left panel of Fig. 1 presents the light-curve, normalized to the mean value. During the campaign, flux is observed to vary within a factor of 3, with significant variability (factor of 2) observed within each epoch. We do not find a strong correlation between the continuum flux and the properties of the wind features found at different epochs. However, there are two facts worth mentioning. On the one hand, epoch-2, the window with the faintest wind features (He I-5876) is the one reaching the highest fluxes. On the other hand, the evolution of epoch-5 (see inset) is affected by the presence of a flare, whose detection is followed by the aforementioned conspicuous wind detections observed in this window (orange dots in the inset). In this regard, we note that even if a similar level of variability is seen in every epoch, this is generally due to fast (non-resolved) flares superposed to a smooth trend, and not to the presence of a single flare as it is the case of epoch-5.

3.2. Search for broad emission line wings

Previous studies have shown that, besides P-Cyg profiles, the presence of broad emission line components can

be also associated with the presence of winds. Given its strength, $H\alpha$ is the best feature to search for the latter. To this end, we have computed the diagnostic diagram developed in Mata Sánchez et al. (2018) for V404 Cyg and subsequently refined in Muñoz-Darias et al. (2019b) for MAXI J1820+070, to which we refer the reader for further details. We performed a Gaussian fit to the $H\alpha$ line profile masking the innermost part of the line (-500 to 500 km s^{-1} in velocity scale), subtracted the fit from the data, and measured the equivalent width (EW) of the residuals in the blue (-2000 to -1000 km s^{-1}) and red (1000 to 2000 km s^{-1}) emission line wings. Significance levels are computed by measuring the *EW of the continuum* within masks of the same width (i.e. 1000 km s^{-1}) in nearby continuum regions. They show a Gaussian distribution from which significance levels can be derived. The diagram is shown in the bottom-right panel of Fig. 1. In order to increase the signal-to-noise ratio, the seven spectra from epoch-1 were averaged and treated as one. As expected, the entire epoch-5 sits outside the 3σ contour, with several spectra located well beyond 5σ , within the P-Cyg region of the plot (i.e. negative blue and positive red residuals). Five spectra from epoch-7 also show significant blue-shifted absorptions, as well as two from epoch-6. In addition, there are two spectra sitting on the bottom-left part of the diagram, showing significant blue absorptions ($> 5\sigma$). All the above can be considered wind detections based on this method. However, none of these detections present significant red wing residuals (i.e. $\gtrsim 0.55$), that is, only the blue-shifted part of the P-Cyg is significantly detected. As a matter of fact, the diagnostic diagram does not show any convincing detection of broad emission line wings (top-right region; $> 5\sigma$). Only two epoch-3 observations (out of 84) clearly exceed the 3σ level (again with non-significant red wing residuals), suggesting that broad emission line components are very weak or not present at all.

4. DISCUSSION

Swift J1858.6-0814 is, after the BH systems V404 Cyg, V4641 Sgr and MAXI J1820+070, the fourth transient LMXB showing optical P-Cyg profiles. Buisson et al. (2020) have recently reported the detection of several X-ray flares consistent with being type I X-ray bursts. If confirmed, this would make Swift J1858.6-0814 the first NS transient showing optical wind signatures, reinforcing the similarities between the outflow phenomenology seen in BH and NS transients (e.g. Ponti et al. 2014 for X-ray winds; Miller-Jones et al. 2010 for jets). In addition, the system has displayed profound, periodic dips/eclipses implying a high inclination and strongly

Table 2. Transient LMXBs with optical P-Cyg profiles

Transient	Period (h)	Inclination (deg)	P-Cyg depth	Terminal velocity (km s ⁻¹)	Outburst	References
V404 Cyg	155.3	60–70	30%	3000	Non-standard	1,2
V4641 Sgr	67.6	60–70	40%	1600 (3000) [†]	Non-standard	3,4
Swift J1858.6-0814	21.8 (?)	Dipping/eclipsing	10%	2400	Ongoing	5, this work
MAXI J1820+070	16.9	60–81	2.5%	1800	Standard	6,7,8

[†]The maximum P-Cyg terminal velocity is ~ 1600 km s⁻¹. However, broad wings reaching ~ 3000 km s⁻¹ were also observed.

References: (1) Casares & Jonker (2014); (2) Muñoz-Darias et al. (2016); (3) Orosz et al. (2001); (4) Muñoz-Darias et al. (2018); (5) Buisson et al. (2020); (6) Torres et al. (2020); (7) Atri et al. (2020); (8) Muñoz-Darias et al. (2019b)

suggesting a relatively long orbital period of 21.8 hours (Buisson et al. 2020).

As in the previous cases, the emission line that displays the most conspicuous wind signatures is He I-5876. This is also one of the best optical wind markers in massive stars and accreting white dwarfs (e.g., Prinja & Fullerton 1994; Kafka & Honeycutt 2004). Our 90 spectra, taken over eight epochs in a time-lapse of five months, show that the optical wind is active during a large fraction of the time, and continuously detected in our data from (at least) epoch-2 (Figs. 1 and 2). Epoch-5 is arguably the most interesting window, with strong wind signatures in both He I-5876 and H α . The blue-shifted absorptions become particularly conspicuous in the last 3 spectra of this epoch, showing also a significant evolution towards high velocities. The inset in the bottom-left panel of Fig. 1 shows the continuum flux evolution during epoch-5. It can be seen that a flare occurs in the middle of the window. Interestingly, the blue-shifted H α absorption almost disappears during the peak (top-right panel in Fig. 1), while the last 3 spectra (orange dots) correspond to the decay of the flare. This behaviour strongly resembles that of V404 Cyg (e.g. fig. 2 in Muñoz-Darias et al. 2016), which showed the strongest P-Cyg profiles during a low luminosity epoch following a flare. However, the terminal velocity was not observed to vary in that case.

In V404 Cyg, the presence and variability of the P-Cyg profiles was found to be correlated with the ionisation state of the outer disc, which is traced by the relative strength of He II to H β emission. In particular, the strongest P-Cyg profiles were found at low ionisation; a conclusion that was also supported by the analysis of MAXI J1820+070 (Muñoz-Darias et al. 2019b). Here, we have also computed the flux ratio of He II to H β (as well as the EWs of He II and Bowen blend) in the 30 spectra taken with the lower resolution grism. Epoch-2 and -3 show variability within a factor of two, roughly following the evolution of the continuum flux, whilst the single value obtained for epoch-5 is in the lower-end of the sample. However, as in the case of the continuum

flux variability, we do not find a clear correlation with the presence/absence of wind features. Nevertheless, given the lack of high-cadence coverage in He II and the similarities between epoch-5 and the behaviour seen in V404 Cyg, we cannot rule out that ionisation effects are a key factor in determining the visibility and properties of the wind.

4.1. Comparison with other LMXBs

Table 2 displays the main wind observables as well as some fundamental system parameters of the four transient LMXB with optical P-Cyg detections. As recently discussed in Hare et al. (2020), the strong flaring activity and variable X-ray absorption of Swift J1858.6-0814 (see also Ludlam et al. 2018; Reynolds et al. 2018) resembles the behaviour of V404 Cyg and V4641 Sgr (see e.g. Kimura et al. 2016; Motta et al. 2017; Morningstar et al. 2014; Gallo et al. 2014; Muñoz-Darias et al. 2018). These two objects display non-standard outbursts characterised by sharp rising phases followed by significant luminosity drops and the absence of steady soft states (e.g. Casares et al. 2019 for V404 Cyg). The discovery outburst of Swift J1858.6-0814 is still ongoing and it is beyond the scope of this paper to discuss the outburst evolution. Nevertheless, the source has been active in radio during the entire optical campaign (van den Eijnden et al. to be submitted), which is one of the standard observables associated with BH (and NS to some extent) hard and intermediate states (e.g. Fender & Muñoz-Darias 2016). This is consistent with the behaviour seen in V404 Cyg, V4641 Sgr and MAXI J1820+070.

Table 2 also reports the maximum terminal velocity and blue-absorption depth observed in the four transients with optical P-Cyg detections. These values are likely biased since (among other things) the observing campaigns (e.g. number and frequency of observations) were significantly different and the wind parameters might also change from outburst to outburst. For instance, the 1989 outburst of V404 Cyg is characterized by lower wind velocities than the 2015 event (Mata Sánchez et al. 2018). Nevertheless, the numbers

suggest that, from a purely observational point of view, the wind signatures of Swift J1858.6-0814 are reminiscent but not as extreme as those found in V404 Cyg and V4641 Sgr, while they significantly exceed those of MAXI J1820+070. This last source displayed a regular outburst evolution (e.g. Shidatsu et al. 2019) and has an orbital period of ~ 17 hours (Torres et al. 2019). A tempting possibility that arises from Table 2 is that larger accretion disks (i.e. \sim long orbital periods) might produce stronger winds, that carry away more mass and/or angular momentum. This could impact on the observed outburst evolution, which at least for the cases of V404 Cyg and V4641 Sgr deviates from the standard patterns typically seen in LMXBs (see e.g. Dunn et al. 2010; Muñoz-Darias et al. 2014 for global studies). Clearly, more observations are required to confirm this speculation. A key system on this matter could be GRS 1915+105 – the BH-LMXB with the longest orbital period (e.g. Corral-Santana et al. 2016) – that have shown some of the best examples of X-ray winds and radio jets (e.g. Neilsen & Lee 2009). Although this very extinguished source cannot be observed at optical wavelengths, sensitive, infrared spectroscopy might be able to shed light on this topic.

Finally, it is worth discussing the role of the orbital inclination in the wind detectability, since it has been found to be a key parameter for X-ray winds, which are best seen at high inclination (Ponti et al. 2012; Díaz Trigo & Boirin 2016). Table 2 shows how optical P-Cygs have been only detected in sources with relatively high inclination ($\gtrsim 60$ deg.; see Higginbottom et al. 2019 for a discussion on the wind geometry and detectability as a function of the line-of-sight). To this list one could add the BH transient Swift J1357.2-0933. This high inclination system has not shown standard P-Cyg profiles, but its characteristic optical dips have been recently found to be associated with broad, blue-

shifted absorptions indicating the presence of an outflow (Jiménez-Ibarra et al. 2019b; Charles et al. 2019).

5. CONCLUSIONS

We have detected clear optical features indicating the presence of an accretion disk wind in the X-ray transient Swift J1858.6-0814. The observational properties of the wind are similar to those observed in V404 Cyg and V4641 Sgr. These systems also share other observables with Swift J1858.6-0814, such as the presence of frequent flares and variable X-ray absorption. As it is the case for other LMXBs with optical wind detections, the outflow is contemporaneous with the radio jet. This work provides additional support for systematic and sensitive optical spectroscopic studies of active X-ray binaries in order to unveil the occurrence rate, observational properties and impact of these cold accretion disk winds.

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REFERENCES

- Atri, P., Miller-Jones, J. C. A., Bahramian, A., et al. 2020, MNRAS, 493, L81, doi: [10.1093/mnras/slaa010](https://doi.org/10.1093/mnras/slaa010)
- Baglio, M. C., Russell, D. M., Pirbhoy, S., et al. 2018, The Astronomer’s Telegram, 12180
- Bandyopadhyay, R. M., Shahbaz, T., Charles, P. A., & Naylor, T. 1999, MNRAS, 306, 417, doi: [10.1046/j.1365-8711.1999.02547.x](https://doi.org/10.1046/j.1365-8711.1999.02547.x)
- Belloni, T. M., Motta, S. E., & Muñoz-Darias, T. 2011, Bulletin of the Astronomical Society of India, 39, 409. <https://arxiv.org/abs/1109.3388>
- Buisson, D. J. K., Hare, J., Guver, T., et al. 2020, The Astronomer’s Telegram, 13563, 1
- Casares, J., Charles, P. A., Jones, D. H. P., Rutten, R. G. M., & Callanan, P. J. 1991, MNRAS, 250, 712
- Casares, J., & Jonker, P. G. 2014, SSRv, 183, 223, doi: [10.1007/s11214-013-0030-6](https://doi.org/10.1007/s11214-013-0030-6)
- Casares, J., Muñoz-Darias, T., Mata Sánchez, D., et al. 2019, MNRAS, 488, 1356, doi: [10.1093/mnras/stz1793](https://doi.org/10.1093/mnras/stz1793)

- Cepa, J., Aguiar, M., Escalera, V. G., et al. 2000, in SPIE Conference Series, Vol. 4008, Optical and IR Telescope Instrumentation and Detectors, ed. M. Iye & A. F. Moorwood, 623–631
- Charles, P., Matthews, J. H., Buckley, D. A. H., et al. 2019, MNRAS, 489, L47, doi: [10.1093/mnras/slz120](https://doi.org/10.1093/mnras/slz120)
- Chaty, S., Charles, P. A., Martí, J., et al. 2003, MNRAS, 343, 169, doi: [10.1046/j.1365-8711.2003.06651.x](https://doi.org/10.1046/j.1365-8711.2003.06651.x)
- Corral-Santana, J. M., Casares, J., Muñoz-Darias, T., et al. 2016, A&A, 587, A61, doi: [10.1051/0004-6361/201527130](https://doi.org/10.1051/0004-6361/201527130)
- Corral-Santana, J. M., Casares, J., Muñoz-Darias, T., et al. 2013, Science, 339, 1048.
<https://arxiv.org/abs/1303.0034>
- Díaz Trigo, M., & Boirin, L. 2016, Astronomische Nachrichten, 337, 368, doi: [10.1002/asna.201612315](https://doi.org/10.1002/asna.201612315)
- Dunn, R. J. H., Fender, R. P., Körding, E. G., Belloni, T., & Cabanac, C. 2010, MNRAS, 403, 61, doi: [10.1111/j.1365-2966.2010.16114.x](https://doi.org/10.1111/j.1365-2966.2010.16114.x)
- Fender, R., & Muñoz-Darias, T. 2016, in Lecture Notes in Physics, Berlin Springer Verlag, Vol. 905, Lecture Notes in Physics, Berlin Springer Verlag, ed. F. Haardt, V. Gorini, U. Moschella, A. Treves, & M. Colpi, 65.
<http://adsabs.harvard.edu/abs/2016LNP...905...65F>
- Fender, R. P., Belloni, T. M., & Gallo, E. 2004, MNRAS, 355, 1105, doi: [10.1111/j.1365-2966.2004.08384.x](https://doi.org/10.1111/j.1365-2966.2004.08384.x)
- Gallo, E., Plotkin, R. M., & Jonker, P. G. 2014, MNRAS, 438, L41, doi: [10.1093/mnras/slt152](https://doi.org/10.1093/mnras/slt152)
- Gehrels, N., Chincarini, G., Giommi, P., et al. 2004, ApJ, 611, 1005, doi: [10.1086/422091](https://doi.org/10.1086/422091)
- Hare, J., Tomsick, J. A., Buisson, D. J. K., et al. 2020, arXiv e-prints, arXiv:2001.03214.
<https://arxiv.org/abs/2001.03214>
- Higginbottom, N., Knigge, C., Long, K. S., Matthews, J. H., & Parkinson, E. J. 2019, MNRAS, 484, 4635, doi: [10.1093/mnras/stz310](https://doi.org/10.1093/mnras/stz310)
- Homan, J., Neilsen, J., Allen, J. L., et al. 2016, ApJL, 830, L5, doi: [10.3847/2041-8205/830/1/L5](https://doi.org/10.3847/2041-8205/830/1/L5)
- Jiménez-Ibarra, F., Muñoz-Darias, T., Casares, J., Armas Padilla, M., & Corral-Santana, J. M. 2019a, MNRAS, 489, 3420, doi: [10.1093/mnras/stz2393](https://doi.org/10.1093/mnras/stz2393)
- Jiménez-Ibarra, F., Muñoz-Darias, T., Armas Padilla, M., et al. 2019b, MNRAS, 484, 2078, doi: [10.1093/mnras/sty3457](https://doi.org/10.1093/mnras/sty3457)
- Kafka, S., & Honeycutt, R. K. 2004, AJ, 128, 2420, doi: [10.1086/424618](https://doi.org/10.1086/424618)
- Kimura, M., Isogai, K., Kato, T., et al. 2016, Nature, 529, 54, doi: [10.1038/nature16452](https://doi.org/10.1038/nature16452)
- Krimm, H., Barthelmy, S., Cummings, J., et al. 2018, The Astronomer’s Telegram, 12151
- Lindstrøm, C., Griffin, J., Kiss, L. L., et al. 2005, MNRAS, 363, 882, doi: [10.1111/j.1365-2966.2005.09483.x](https://doi.org/10.1111/j.1365-2966.2005.09483.x)
- Ludlam, R., Miller, J., Arzoumanian, Z., et al. 2018, The astronomer’s telegram, 12158
- Mata Sánchez, D., Muñoz-Darias, T., Casares, J., et al. 2018, MNRAS, 481, 2646, doi: [10.1093/mnras/sty2402](https://doi.org/10.1093/mnras/sty2402)
- McClintock, J. E., & Remillard, R. A. 2006, Black hole binaries, ed. W. H. G. Lewin & M. van der Klis, 157–213.
<http://adsabs.harvard.edu/abs/2006csxs.book..157M>
- Miller, J. M., Raymond, J., Fabian, A., et al. 2006, Nature, 441, 953, doi: [10.1038/nature04912](https://doi.org/10.1038/nature04912)
- Miller-Jones, J. C. A., Sivakoff, G. R., Altamirano, D., et al. 2010, ApJL, 716, L109, doi: [10.1088/2041-8205/716/2/L109](https://doi.org/10.1088/2041-8205/716/2/L109)
- Mirabel, I. F., & Rodríguez, L. F. 1999, Ann. Rev. Astron. Astrophys., 37, 409, doi: [10.1146/annurev.astro.37.1.409](https://doi.org/10.1146/annurev.astro.37.1.409)
- Morningstar, W. R., Miller, J. M., Reynolds, M. T., & Maitra, D. 2014, ApJL, 786, L20, doi: [10.1088/2041-8205/786/2/L20](https://doi.org/10.1088/2041-8205/786/2/L20)
- Motta, S. E., Kajava, J. J. E., Sánchez-Fernández, C., Giustini, M., & Kuulkers, E. 2017, MNRAS, 468, 981, doi: [10.1093/mnras/stx466](https://doi.org/10.1093/mnras/stx466)
- Muñoz-Darias, T., Fender, R. P., Motta, S. E., & Belloni, T. M. 2014, MNRAS, 443, 3270, doi: [10.1093/mnras/stu1334](https://doi.org/10.1093/mnras/stu1334)
- Muñoz-Darias, T., Casares, J., Mata Sánchez, D., et al. 2016, Nature, 534, 75, doi: [10.1038/nature17446](https://doi.org/10.1038/nature17446)
- Muñoz-Darias, T., Jiménez-Ibarra, F., Armas Padilla, M., et al. 2019a, The Astronomer’s Telegram, 12881
- Muñoz-Darias, T., Torres, M. A. P., & Garcia, M. R. 2018, MNRAS, 479, 3987, doi: [10.1093/mnras/sty1711](https://doi.org/10.1093/mnras/sty1711)
- Muñoz-Darias, T., Casares, J., Mata Sánchez, D., et al. 2017, MNRAS, 465, L124, doi: [10.1093/mnras/slw222](https://doi.org/10.1093/mnras/slw222)
- Muñoz-Darias, T., Jiménez-Ibarra, F., Panizo-Espinar, G., et al. 2019b, ApJL, 879, L4, doi: [10.3847/2041-8213/ab2768](https://doi.org/10.3847/2041-8213/ab2768)
- Neilsen, J., & Lee, J. C. 2009, Nature, 458, 481, doi: [10.1038/nature07680](https://doi.org/10.1038/nature07680)
- Orosz, J. A., Kuulkers, E., van der Klis, M., et al. 2001, ApJ, 555, 489, doi: [10.1086/321442](https://doi.org/10.1086/321442)
- Paice, J. A., Gandhi, P., Dhillon, V. S., et al. 2018, The Astronomer’s Telegram, 12197, 1
- Ponti, G., Fender, R. P., Begelman, M. C., et al. 2012, MNRAS, 422, L11, doi: [10.1111/j.1745-3933.2012.01224.x](https://doi.org/10.1111/j.1745-3933.2012.01224.x)
- Ponti, G., Muñoz-Darias, T., & Fender, R. P. 2014, MNRAS, 444, 1829, doi: [10.1093/mnras/stu1742](https://doi.org/10.1093/mnras/stu1742)
- Prinja, R. K., & Fullerton, A. W. 1994, ApJ, 426, 345, doi: [10.1086/174070](https://doi.org/10.1086/174070)
- Rahoui, F., Coriat, M., & Lee, J. C. 2014, MNRAS, 442, 1610, doi: [10.1093/mnras/stu977](https://doi.org/10.1093/mnras/stu977)

- Reynolds, M., Miller, J., Ludlam, R., & Tetarenko, B. 2018, The Astronomer's Telegram, 12220
- Shidatsu, M., Nakahira, S., Murata, K. L., et al. 2019, ApJ, 874, 183, doi: [10.3847/1538-4357/ab09ff](https://doi.org/10.3847/1538-4357/ab09ff)
- Soria, R., Wu, K., & Hunstead, R. W. 2000, ApJ, 539, 445, doi: [10.1086/309194](https://doi.org/10.1086/309194)
- Torres, M. A. P., Casares, J., Jiménez-Ibarra, F., et al. 2020, submitted to ApJ, arXiv:2003.02360. <https://arxiv.org/abs/2003.02360>
- . 2019, ApJL, 882, L21, doi: [10.3847/2041-8213/ab39df](https://doi.org/10.3847/2041-8213/ab39df)
- van der Klis, M. 2006, 39
- Vasilopoulos, G., Bailyn, C., & Milburn, J. 2018, The Astronomer's Telegram, 12164