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Outburst evolution of the black hole transient Swift J1727.8-1613.

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We present an extensive optical/NIR spectroscopic campaign of the black hole transient Swift J1727.8-1613 during its 2023–2024 discovery outburst, using 13 mid/high resolution spectra obtained with VLT/X-Shooter. The observations trace the system through its hard-to-soft and soft-to-hard state transitions. We report the detection of sporadic, symmetric absorption troughs in Balmer emission line wings during the bright states, which we interpret as signatures of optically thick regions within the accretion disc rather than a wind. Through analysis of the He II λ4686 Å line, which is a good tracer of the chromospheric emission from the disc, we identify a distinct morphological change during the peak of the radio flaring period, consistent with the "reheating" of the outer disc, probably associated with a discrete jet ejection. Finally, we detect the emergence of broad, blue-shifted absorption features during the transition back to the low-hard state. We interpret these features, distinctly detected in higher-order lines from the Balmer series, as the likely signature of a massive, cool accretion disc wind, with a characteristic velocity of $\approx 800\,\mathrm{km\,s^{-1}}$, which is thought to be absorbing the blue component from a disc-formed line in He II λ4686 Å during this epoch.

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1. Introduction

Low-mass X-ray binaries (LMXBs) are systems where a compact object, either a black hole (BH) or a neutron star, accretes matter from a low-mass companion star. The material forms an accretion disc [1] that dissipates gravitational potential energy, radiating primarily in X-rays. These systems undergo sporadic outbursts driven by thermal-viscous instabilities in the disc, during which their brightness increases by several magnitudes in optical wavelengths [2]. While X-ray observations probe the hot, inner regions of the accretion flow, UV, optical and near-infrared (NIR) spectroscopy provides a powerful diagnostic for the geometry, kinematics, and evolution of the outer disc [3].

Outflows are a ubiquitous feature of these outbursts, they are commonly observed as either collimated, relativistic jets that dominate the radio band during hard states [4] or accretion disc winds, which usually manifests differently depending on the state. In soft states, they are detected as hot, ionized winds via X-ray absorption lines [5, 6], while in harder states, they appear as cooler, denser winds observed via blue-shifted absorption and broad optical/NIR emission line wings [7, 8]. The existence of these hot and cold winds has been well documented in multiple LMXBs, but it is unclear whether they are distinct winds seen at different stages of the outburst or the same outflow viewed at different wavelengths. Recent detections of multi-phase winds favour the latter interpretation [9, 10]. Understanding these disc winds is key to the accretion process itself, as they carry away significant amounts of mass and angular momentum, ultimately shaping the outburst's behaviour, and may play an important role in the suppression of the radio emission from the compact jet [11, 12].

Swift J1727.8-1613 was discovered on August 24, 2023 [13]. Initially classified as a Gamma-Ray Burst (GRB 230824A) due to its remarkable brightness, it was quickly re-identified as a Galactic BH LMXB after its X-ray flux rapidly increased, reaching over 2 crab at 2-10 keV [14]. Its X-ray properties, similar to that of BH XRB V404 Cygni [15], triggered intensive multi-wavelength follow-up campaigns. In this work, we present an extensive optical/NIR spectroscopic campaign covering the entirety of its discovery outburst.

2. VLT/X-Shooter

We obtained 13 mid-resolution spectra of *Swift* J1727.8-1613 using the X-Shooter spectrograph [16] on the VLT between August 27, 2023, and March 24, 2024. X-Shooter provides simultaneous coverage from 3000 Å to 2.4 μm across its UVB, VIS, and NIR arms. The campaign was split into two programs: the first (PID 111.265Y) covered the outburst rise and hard-to-soft transition, while the second (PID 112.26W7) observed the decay and soft-to-hard transition.

The data were reduced using the standard X-Shooter pipeline within the `EsoReflex`[1][17] environment. Telluric absorption was corrected using *molecfit* [2] [18]. All wavelengths and times were converted to the barycentric rest frame and corrected for the systemic velocity of $\gamma = -178 \pm 3$ km s^{-1} [19]. Extinction correction was derived from near-UV spectroscopy [$E(B-V) = 0.37 \pm 0.01(stat) \pm 0.025(sys)$; 20].

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[1] EsoReflex

[2] Molecfit

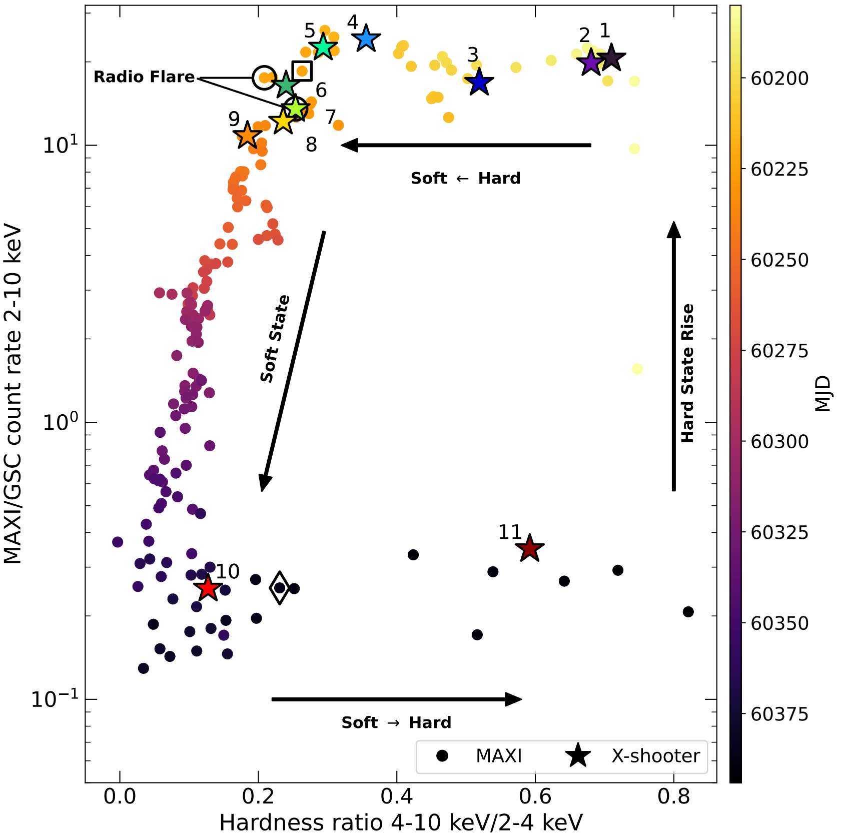

Figure 1: Hardness-intensity diagram of *Swift* J1727.8-1613 during its discovery outburst. The y-axis displays the Monitor of All-sky X-ray Image Gas Slit Camera (MAXI/GSC) count rate in the 2-10 keV band, and the x-axis shows the hardness ratio, defined as the ratio of count rates in the 4-10 keV and 2-4 keV bands. The filled circles represent the MAXI observations, color-coded by the Modified Julian Date (MJD) as indicated by the right color bar. The solid black arrows indicate the temporal evolution of the outburst through the different accretion states. The 11 spectroscopic epochs gathered with X-shooter are marked with numbered stars, where epochs 10 and 11 consist of two consecutive observations each. The open circles represent the peak of the two bright radio flares reported by Hughes et al. 2025 [21]. The open square highlights the onset hard-to-soft state transition [22, 23] while the open diamond indicates the onset soft-to-hard state transition [24]

3. Results

Swift J1727.8-1613 followed the canonical 'q'-shaped hysteresis pattern in the Hardness-Intensity Diagram (HID), typical of transient BH LMXRBs [4]. Figure 1 shows the MAXI/GSC light curve and hardness ratio, with our X-Shooter observations marked. Epochs 1-5 sample the high-luminosity hard state, while epochs 6-9 cover the high luminosity soft state. Two more visits were obtained when it emerged from the sun glare, where the luminosity had declined by a factor of ~ 100 compared to the previous epochs. The first one (epoch 10), was observed during the soft state, the last visit (epoch 11), was obtained towards the end of the soft-to-hard transition

3.1 Absorption Troughs in the Bright-Hard to Soft State

Figure 2 presents a detailed view of several characteristic spectral lines, spanning different ionization states, plotted in velocity space, including key Balmer and Helium lines. In the first observation (epoch 1), obtained approximately 48 hours after the MAXI alert, the prominent Hydrogen lines exhibited a strong red-velocity skew. In contrast, the higher-ionization He II λ4686 Å line showed a more symmetric, double-peaked profile. During the subsequent observations (epochs 2-9), all lines consistently relaxed into the conventional double-peaked morphology characteristic of a rotating accretion disc [25]. Throughout these later epochs, the Balmer lines also sporadically displayed low-amplitude absorption troughs in their wings. As illustrated in the first column of Figure 2, these blue and red-sided troughs emerge at comparable velocities ($\sim \pm 1000\,\mathrm{km\,s^{-1}}$) and retain their symmetry relative to the line's rest position, even as their depth fluctuates. While a previous interpretation suggested these features were distinct inflows and outflows [26], their simultaneous and symmetrical nature points to an alternative origin. To test this, we performed fits on the Hα line wing troughs with broad Gaussian profiles, where the absorption strength was sufficient for analysis. Our results confirm the troughs remained symmetric about the system's rest velocity (excluding epoch 7). This behaviour argues against a classical P Cygni-type (or reverse P-Cygni) wind. Instead, it suggests the presence of optically thick regions within the accretion disc, reminiscent of a stellar atmosphere, that produce a broad absorption profile, embedded with an emission component from either a hotter, irradiated disc atmosphere [27], probably with contribution from emission lines originated in the irradiated face of the donor and the disc-stream impact region (aka hotspot).

To trace the evolution of the ionised outer accretion disc, we measured flux, peak-to-peak separation, and FWHM of the He II line, as well as the FWHM of Hα for comparison. The evolution of these measurements are plotted in Figure 3. In this Figure we can see a general trend during the hard-to-soft state transition where the FWHM (and peak-to-peak) separation of He II increases and the line strength decreases, suggesting a contracting line-emitting region . In the case of Hα, its FWHM (as measured from the continuum level) exhibits an opposite trend, i.e. decreasing as the source softens. This strengthens the interpretation of the presence of a photospheric broad absorption in Hα, because even though the emission line profile is broadening as the line-emitting regions contracts, traced by He II, the apparent decrease in FWHM in Hα is produced by the weakening of the emission component that is embedded in the broad absorption.

3.2 The Disc's Response to the Radio Flaring

The observations for epochs 6–8 coincide with the onset of the soft state and the radio flaring period associated with bipolar jet ejections [e.g. 28]. From figure 3, we see that as the source softened, the He II line's integrated flux gradually decreased, while its FWHM and peak separation remained constant, indicating a stable disc. This stability ceased around epoch 6 (the onset of the soft state), where line flux dropped by a factor of two, and both FWHM and peak separation increased sharply, indicative of the depletion of the outer disc as the source softens. Epoch 7 is particularly notable, as it was observed within ~12 hours of the peak luminosity of the brightest radio flare reported by Hughes et al. 2025 [21], which reached $\sim$ 800 mJy at 1.28 GHz. Here, the He II flux showed a small but significant increase, while both its FWHM and peak separation

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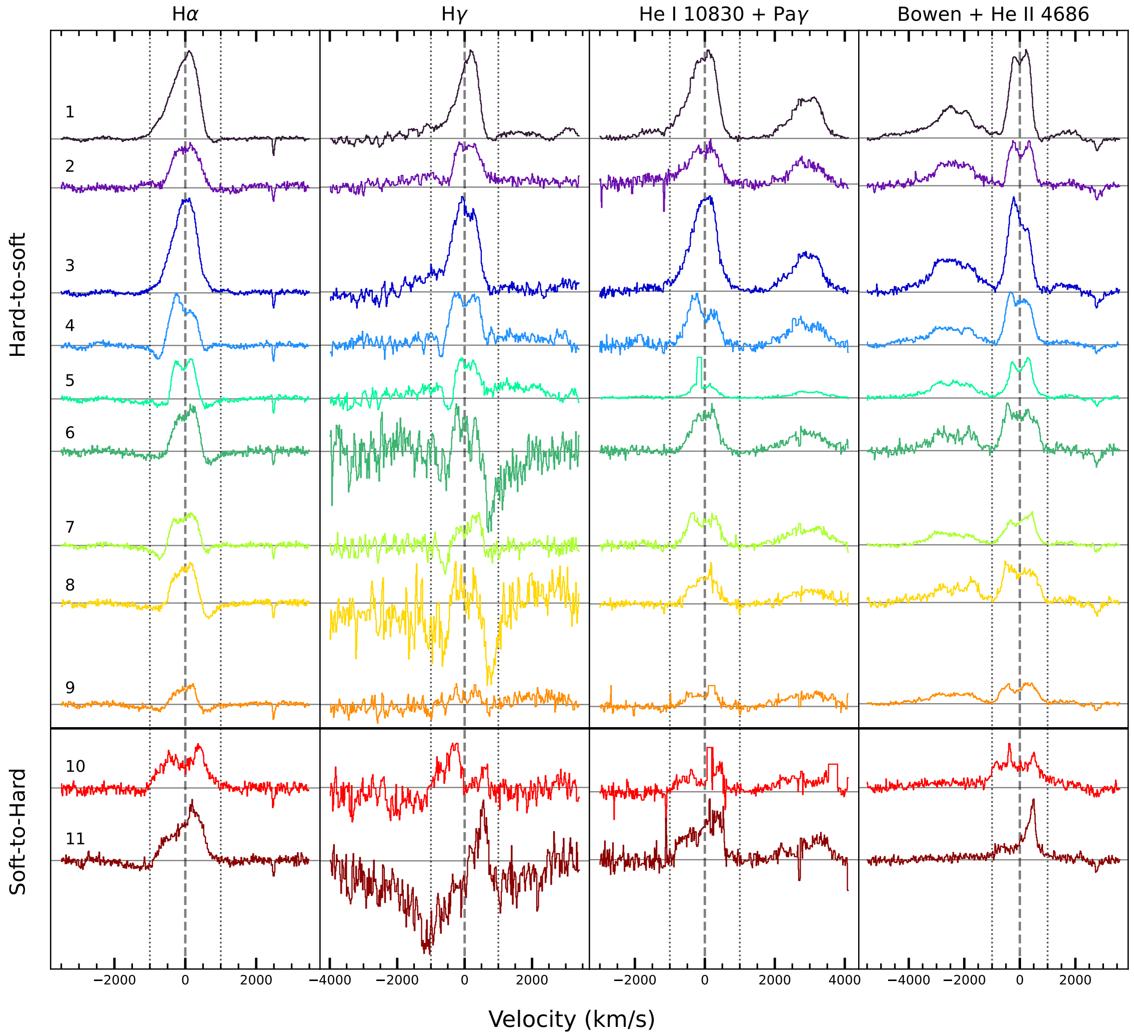

Figure 2: Continuum-normalized, velocity-resolved line profiles of *Swift* J1727.8-1613 across the 11 X-shooter observing epochs. From left to right, the panels show Hα, Hδ, He I λ10830 Å and the He II λ4686 Å line alongside the Bowen blend; the latter three are re-normalized to the Hα peak flux for clarity. The colour and number of each observation corresponds to the same epoch shown in Figure 1. Dashed lines indicate zero velocity, while dotted lines in each panel mark the approximate positions of transient absorption features on either side of the emission profiles, intended as a qualitative guide.

decreased. This behaviour suggests that the ionisation structure of the outer accretion disc may be reacting to the radio flares. If radiation from the jet ejection temporarily irradiates the outer disc, it could heat up these regions and shift the dominant line-emitting region to larger radii. This shift corresponds to lower Keplerian velocities, naturally resulting in a narrower line profile (smaller FWHM and peak separation) and a temporary increase in the line luminosity. The flaring event may also account for the asymmetry of the broad absorption seen in the Hα line profile in epoch 7, which is blueshifted to $-271 \pm 46\,\mathrm{km\,s^{-1}}$. This velocity offset suggests a slowly approaching, optically thick component along the line of sight, which may be associated with the discrete jet ejection.

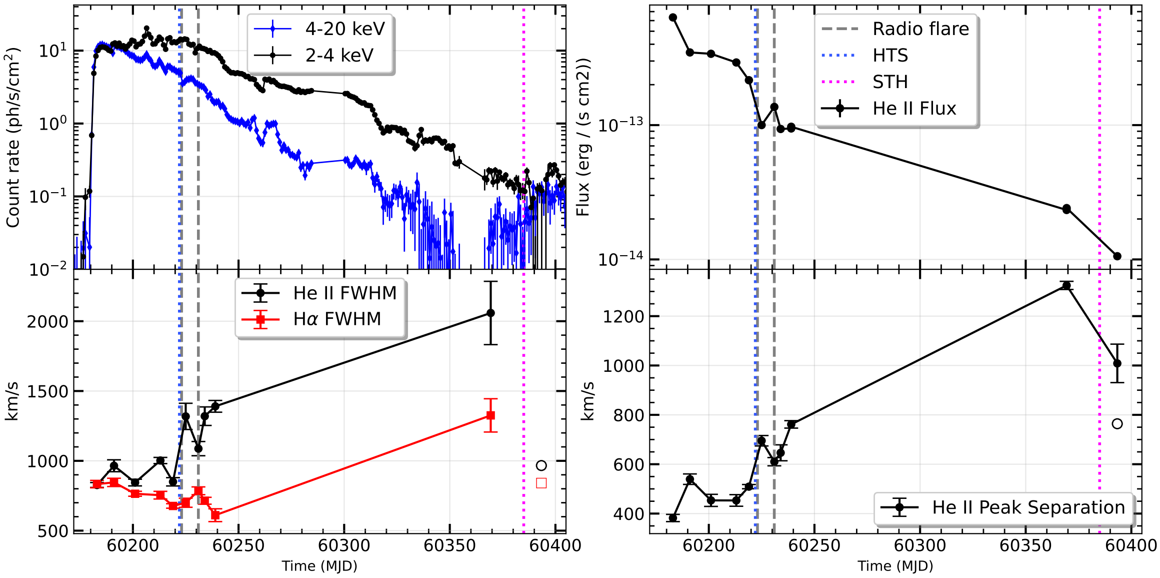

Figure 3: Temporal evolution of the He II λ4686 line and X-ray count rate. The panels display the count rate (top left), He II flux (top right), FWHM (bottom left), and peak separation (bottom right). Vertical dashed lines mark the brightest radio flares. Blue and magenta dotted lines indicate the hard-to-soft and soft-to-hard transitions, respectively. Error bars are included (if not visible, they are smaller than the markers). For the asymmetric final epoch: the FWHM of He II (open black circle) and Hα (open red square) is estimated as 2× the red peak's separation from rest velocity (i.e., mirroring the peak). The open circle in the bottom right panel shows the peak-to-peak separation, also estimated by mirroring the red peak.

3.3 Emergence of A Massive Outflow During Soft-to-Hard Transition

The final two observations showed the system in a fading state, where the luminosity had reduced by a factor of ~100 in the 2-10 keV band compared to the bright-hard state, as evident in Figure 1. By Epoch 10 the He II flux had dropped by a factor of ~10 since the hard-to-soft state transition, and the Bowen blend was absent. A narrow emission component at $\sim 500\,\mathrm{km\,s^{-1}}$ also became visible in the He II line during epoch 10. This feature is coincident with the position of the donor star in velocity space, derived from the orbital solutions from Mata Sánchez et al. 2025 [19], and is therefore likely associated with the irradiated face of the donor star or the hotspot. A dramatic change then occurred in epoch 11, which captured the soft-to-hard transition, where strong, broad absorption features emerged in the higher-order Balmer lines (particularly in Hγ) that were previously dominated by emission. We primarily interpret these broad, blue-shifted absorption features as the signature of a massive, cool accretion disc outflow. However, it is possible that they originate from localized, optically thick regions within the accretion disc itself, reminiscent of the symmetric troughs seen during the earlier bright states. We fit this feature in Hγ using two methods to handle the existing emission cores: (i) fitting only the wings (masking the core) and (ii) a multi-component fit (using Gaussians for the cores), with the broad absorption modelled by Lorentzians. Regardless of the approach, both methods yield statistically consistent centroid velocity within 1σ (i.e,-883.94 ± 86.05 and -754.39 ± 112.36, respectively). The He II line profile in epoch 11 transformed as well, losing its blue peak almost entirely and leaving only a single red-shifted component accompanied by a broad base slightly rising above the continuum. This remaining red peak aligns with the red peak from epoch 10 in the velocity space, and the rise of the broad base roughly matches the peak of the blue component. This suggests that the same material producing the broad Balmer absorption is also responsible for obscuring the blue wing of the He ii line.

4. Summary and Conclusions

We present 11 epochs of X-shooter spectroscopy tracking the optical evolution of *Swift* J1727.8-1613. We detected sporadic, variable absorption troughs in the Balmer line wings during the bright-hard and soft states. These features are symmetric about the line center at $\sim \pm 1000$ km s^{-1}, and alongside the opposing trends in the FWHM of He II and Hα, support a two-component model where broad absorption from an optically thick disc region is superimposed with an emission core from (or a combination of) either an irradiated atmosphere above the disc, the irradiated face of the donor star or the hotspot. We observed a significant morphological change in the He ii line coincident with the system's strongest radio flare. During this event, the line flux increased while the FWHM and peak-to-peak separation decreased. We interpret this as the accretion disc's response to the launch of bipolar ejecta, which irradiated and reheated the outer disc and temporarily shifted the dominant He ii emission region to lower Keplerian velocities. Finally, we report the emergence of broad, blue-shifted absorption features in the higher-order Balmer lines during the transition to the low-hard state. With a characteristic bulk velocity of $\approx 800\ km\ s^{-1}$, we interpret these features as the likely signature of a massive, cool disc outflow, though an origin from localized optically thick regions within the disc remains a possibility. The simultaneous suppression of the blue peak in the He ii profile suggests the same material producing the broad Balmer absorption is also responsible for absorbing the underlying disc emission.

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