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BASS XXXIX: *Swift*-BAT AGN with changing-look optical spectra

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ABSTRACT

Changing-look (CL) AGN are unique probes of accretion onto supermassive black holes (SMBHs), especially when simultaneous observations in complementary wavebands allow investigations into the properties of their accretion flows. We present the results of a search for CL behaviour in 412 *Swift*-BAT detected AGN with multiple epochs of optical spectroscopy from the BAT AGN Spectroscopic Survey (BASS). 125 of these AGN also have 14–195 keV ultra-hard X-ray light curves from *Swift*-BAT which are contemporaneous with the epochs of optical spectroscopy. Eight CL events are presented for the first time, where the appearance or disappearance of broad Balmer line emission leads to a change in the observed Seyfert type classification. Combining with known events from the literature, 21 AGN from BASS are now known to display CL behaviour. Nine CL events have 14–195 keV data available, and five of these CL events can be associated with significant changes in their 14–195 keV flux from BAT. The ultra-hard X-ray flux is less affected by obscuration and so these changes in the 14–195 keV band suggest that the majority of our CL events are not due to changes in line-of-sight obscuration. We derive a CL rate of 0.7–6.2 per cent on 10–25 yr time-scales, and show that many transitions happen within at most a few years. Our results motivate further multiwavelength observations with higher cadence to better understand the variability physics of accretion onto SMBHs.

Key words: galaxies: active.

1 INTRODUCTION

In the simplest unified model for active galactic nuclei (AGN), orientation determines their observed properties (Antonucci 1993; Urry & Padovani 1995). When the obscuring toroidal material is

blocking the line of sight, soft X-ray, ultraviolet, and optical emission from the nucleus is absorbed, as is light from the broad emission line region (BLR); only narrow line emission is observed in the ultraviolet and optical. While the unified model can explain many observed properties of AGN, a growing number of highly variable sources challenge the simplest version of this model. Such ‘changing-look’ (CL) AGN experience rapid changes in their optical, ultraviolet, or X-ray classification. In the rest-frame optical and ultraviolet, AGN

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have been seen to rapidly change between different Seyfert spectral type classifications: from a type 1 source with strong, broad emission lines to a type 2 source with only narrow emission lines or vice versa (Collin-Souffrin, Alloin & Andriolat 1973; Shappee et al. 2014; LaMassa et al. 2015; Ruan et al. 2016; Runco et al. 2016; Yang et al. 2018; MacLeod et al. 2019; Graham et al. 2020; Guo et al. 2020; Senarath et al. 2021; López-Navas et al. 2022). In multi-epoch X-ray observations, AGN have been seen to change from Compton-thick to Compton-thin or vice versa, consistent with a large change in the amount of material which is obscuring the line-of-sight to the continuum source (e.g. Guainazzi 2002; Matt, Guainazzi & Maiolino 2003; Marchese et al. 2012; Ricci et al. 2016).

However, changes in line-of-sight obscuration can only account for a subset of CL AGN. In some of these objects, known as ‘changing-state’ (CS) AGN, changes in the structure of the accretion disc are required to explain the characteristics of the observed variability. For example, Stern et al. (2018) showed that the mid-infrared emission was highly variable in the CS quasar WISE J105203.55+151929.5 on time-scales of only a few years – significantly shorter than would be expected for an obscurer to cover the mid-infrared emitting region. While the geometry of the accretion flow will vary with large changes in the accretion rate (Narayan & Yi 1995; Yuan & Narayan 2014; Giustini & Proga 2019; Ruan et al. 2019), such changes are expected to occur on the viscous time-scale, which is tens to thousands of years in the discs around supermassive black holes (SMBHs). The changes observed in CS AGN often occur within tens of months, which is closer to the thermal time-scale (e.g. Gezari et al. 2017), suggesting that this behaviour is driven by temperature variations or instabilities in the inner accretion disc (Noda & Done 2018; Ross et al. 2018). CS AGN are thus an important probe of accretion disc physics, especially when coupled with multiwavelength observations in the rest-frame X-ray, ultraviolet, optical, and infrared which probe the different line- and continuum-emitting regions around the SMBH.

Over the past years, more than one hundred CL AGN have been discovered at various redshifts, but only a few of these objects have been studied in detail in the X-ray band. Most famously, the appearance and disappearance of broad optical lines in Mrk 1018 (Cohen et al. 1986; McElroy et al. 2016) have been associated with the evolution of the X-ray–ultraviolet continuum emission which is responsible for photoionizing the BLR gas (Noda & Done 2018; Lyu et al. 2021; Liu, Wu & Lyu 2022). More dramatic behaviour was observed in IES 1927+654, which underwent a complete transformation of its X-ray spectral properties, and showed X-ray variability of over four orders of magnitude on time-scales of months (Trakhtenbrot et al. 2019; Ricci et al. 2020, 2021). However, due to the relatively small number of CS AGN observed in the X-rays, it is still unclear whether these events are always accompanied by a clear transition in the X-ray band. It is therefore critical to identify more examples of AGN which both show changes in their optical spectral type classification and also have contemporaneous multiwavelength data which can be used to constrain the physics of CL and CS AGN transitions.

At the same time, we are moving from serendipitous discoveries to an era of systematically searching for CL behaviour in large surveys. Most CL AGN studies to date have looked for changes in the emission properties of a parent sample which has been selected using optical data. Such searches tend to be biased towards finding either the appearance of broad lines in previously known type 2 objects (the so-called ‘turn-on’ events), or the disappearance of broad emission features from previous type 1 objects (‘turn-off’ events). For example, recent work from the SDSS-IV TDSS survey found 15 turn-off and 4 turn-on CL AGN, starting from a sample of 64 039

broad-line SDSS quasars (Green et al. 2022). A complementary search by Hon et al. (2022) found 24 turn-on and 4 turn-off CL AGN, starting from a sample of 1092 type 2 and 304 type 1 AGN in the 6dF Galaxy Survey. To better understand the incidence of CL, and specifically CS behaviour, it is therefore desirable to search within a parent sample that was not selected based on ultraviolet or optical properties, thus being less biased towards either of the main spectral AGN sub-classes (type 1 or type 2 AGN).

The Burst Alert Telescope (BAT; Barthelmy et al. 2005) onboard the *Swift* satellite (Gehrels et al. 2004) has been scanning the sky in the 14–195 keV X-ray band since 2004 December. The BAT AGN Spectroscopic Survey (BASS; Koss et al. 2022a) is a comprehensive, multiwavelength effort to investigate the properties of local AGN selected via their *Swift*-BAT 14–195 keV X-ray emission. This ultra-hard X-ray selection is far less biased by obscuration (fig. 1 of Ricci et al. 2015), effectively ensuring a complete census of actively accreting SMBHs in the local universe. The second data release (DR2) from BASS focuses on the 858 AGN (Koss et al. 2022b) from the 70-month *Swift*-BAT catalogue (2004 December to 2010 October; Baumgartner et al. 2013). BASS DR2 includes 1449 optical spectra for these 858 objects, from which have been derived emission line measurements, black hole masses, and accretion rates (den Brok et al. 2022; Koss et al. 2022b,c; Mejía-Restrepo et al. 2022; Oh et al. 2022; Ricci et al. 2022a,b). Due to their bright fluxes, BASS AGN are some of the most well-studied AGN in the universe, with detailed observations across all wavebands in many cases. This sample therefore provides an excellent test bed for constraining the physics of CL AGN.

In this paper, we present a sample of eight new CL events identified through visual inspection of 412 AGN with ≥ 2 epochs of optical spectroscopy in the BASS DR1 and DR2 catalogues. We also discuss the ultra-hard X-ray light curves of five previously known CL AGN from the BASS sample; four from the 70-month BAT catalogue which formed the basis for BASS DR2, and one additional object from the 105-month BAT catalogue (Oh et al. 2018). In Section 2, we describe the data set and the methods used to identify the sample of CL AGN, which we present in Section 3. These objects are discussed and compared to previously known populations in Section 4. Throughout this work, we assume a flat concordance cosmology with $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$, $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, consistent with previous papers from the BASS collaboration.

2 DATA

2.1 Optical spectra

We start from a sample of 2168 unique optical spectra covering 1105 unique BAT-detected AGN, consisting of the complete BASS DR1 and DR2 catalogues (Koss et al. 2017; Koss et al. 2022b) as well as additional, unpublished observations obtained as part of the ongoing BASS effort to study newly identified AGN in the BAT 105-month survey. Blazars (Paliya et al. 2019; Marcotulli et al. 2022) and other types of beamed AGN were then removed, using the classifications reported in the Koss et al. (2022b) catalogue. High spectral resolution observations with limited wavelength coverage, typically only $\approx 8000\text{--}9000 \text{ \AA}$, were also discarded. Such spectra were taken to measure stellar velocity dispersions via the Calcium triplet absorption complex and do not cover the broad Balmer emission lines. From the remaining data, 430 BAT sources have multiple epochs of optical spectroscopy. The merging system Was 49 (BAT ID 605) has one spectrum from each of its two nuclei in the BASS DR2 catalogue and is removed from our sample. 17 sources

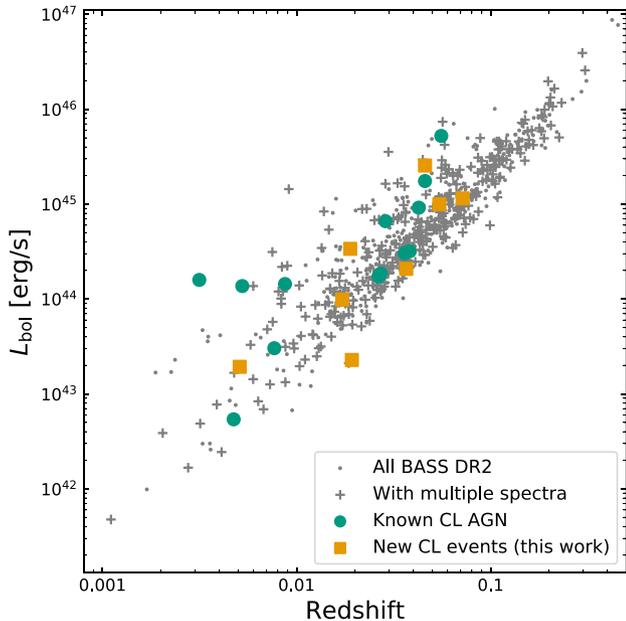


Figure 1. Distribution in redshift–luminosity space for BASS DR2, with the parent sample for this investigation marked with crosses. Previously known and newly identified CL AGN (see Section 3) are identified with coloured symbols. We do not see any changes in type in BASS AGN with redshifts $z > 0.1$, which are among the most luminous objects in our parent sample.

have redshifts $z > 0.5$, where their observed-frame optical spectra cover the rest-frame ultraviolet regime. Such objects were inspected separately, and no significant changes were observed in their rest-ultraviolet emission features.

Following these cuts, we have 412 AGN from BASS DR2 with multiple epochs of rest-frame optical spectroscopy, which form the parent sample for this investigation. Within this parent sample, the median number of spectral epochs per object is 3. These sources cover the full range of $L_{\text{bol}} (\approx 10^{42-47} \text{ erg s}^{-1})$, $M_{\text{BH}} (\approx 10^{6-9.5} M_{\odot})$, and $L/L_{\text{Edd}} (\approx 10^{-4} - 10^1)$ of the BASS DR2 population, as shown in Figs 1 and 2.

Each of these 412 AGN were visually inspected for changes in their Balmer line ($H\beta$ and/or $H\alpha$) properties. Due to the heterogeneity of the spectroscopic data for our sample, acquired using 24 different instruments and 18 different telescopes, the accuracy of the spectrophotometry (i.e. the absolute flux calibration) of each spectrum varies considerably. Throughout this work we therefore normalize the flux in each spectral band (i.e. around $H\beta$ and $H\alpha$) by dividing out the median flux, to better visualize the changes in the emission lines. Any change in the seeing or the aperture size (slit width or fibre diameter) will lead to a change in the relative contribution from the host galaxy to the flux of the extracted spectrum, and hence a change in the equivalent width of any nuclear emission features. However, each spectrum in our parent sample covers the nucleus of the galaxy and so if broad line emission is present then we expect to detect it. The aim of this work is to find high-confidence CL AGN in BASS spectra, and to analyse those which could be due to CS behaviour, but not to accurately quantify their emission line properties. To mitigate the effects of varying signal-to-noise ratio, spectral resolution, instrument, and flux calibration, herein we present only objects which were seen with complete changes in spectral type, i.e. the complete appearance or disappearance of broad $H\beta$ or $H\alpha$ emission lines (Fig. 3). In Appendix A, we show

examples of spectra which did not meet this criteria and so were discarded during our visual inspection process.

2.2 BAT light curves

While the AGN in BASS DR2 were selected from the first 70 months of the BAT survey, data are now available covering the first 157 months of *Swift* operations, from 2004 December to 2017 December (Lien et al., in preparation). We rebin each light curve to 6-month bins to improve the signal-to-noise ratio and to aid the identification of longer term trends in the 14–195 keV emission.

From our parent sample of 412 AGN, 162 spectral epoch-pairs from 125 objects occur within the period 2004 December to 2017 December. The vast majority of the remaining 287 objects have only one spectrum from before 2017 December with subsequent spectral epochs (usually from targeted BASS programmes) dating from 2018 January onwards. We therefore have X-ray light curves contemporaneous with multi-epoch optical spectra in 125 AGN, making this the largest search for CL AGN to date from simultaneous optical and X-ray multi-epoch data.

2.3 Black hole masses and Eddington ratios

We use the black hole mass (M_{BH}) estimates from the BASS DR2 catalogue. These measurements are described in detail by Koss et al. (2022b), and here we only briefly discuss these estimates. M_{BH} estimates are taken from (i) literature measurements of spatially resolved megamasers, stellar or gas dynamics, or reverberation mapping campaigns; (ii) single-epoch measurements of broad emission lines (Mejía-Restrepo et al. 2022); and (iii) measurements of stellar velocity dispersions (Koss et al. 2022c) and assuming the Kormendy & Ho (2013) $M_{\text{BH}} - \sigma_*$ relation.

Due to the variable nature of the CL AGN studied in this work, the question naturally arises as to whether the BLR in these objects is virialized and whether the usual virial scaling relations used for broad emission lines hold true. In the right-hand panel of Fig. 2 we show the subset of the catalogue with σ_* -derived M_{BH} . As would be expected, these sources do not include many of the brightest AGN inferred to have $L/L_{\text{Edd}} \gtrsim 1$, but do cover the full range of parameter space spanned by the CL AGN in this work. Recently Jin, Wu & Feng (2022) showed that the virial M_{BH} estimated from the bright epochs in a sample of 26 CL AGN is consistent with the M_{BH} inferred from measurements of stellar velocity dispersions in their faint epochs, suggesting both that (i) CL AGN follow the usual $M_{\text{BH}} - \sigma_*$ relation and (ii) the virial scaling relations used to derive M_{BH} are still applicable in CL AGN. The dominant uncertainty on each M_{BH} estimate is of the order of 0.45 dex due to the systematic uncertainties in virial and σ_* scaling relations (Shen 2013; Koss et al. 2022b). This gives rise to the covariant uncertainty ellipse in the $M_{\text{BH}} - L/L_{\text{Edd}}$ space shown in Fig. 2.

For the time-variable sources studied in this work, any estimation of the Eddington ratio also requires knowledge of the instantaneous bolometric luminosity L_{bol} . For spectra taken between 2005 and 2017 (inclusive), we infer an estimate of L_{bol} using the relevant *Swift*-BAT 14–195 keV light curve, assuming 1 Crab is $2.3343 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$ (Oh et al. 2018), a $\Gamma = 1.8$ continuum power-law index (Ricci et al. 2017), and a bolometric correction consistent with previous BASS works (Vasudevan & Fabian 2009; Koss et al. 2022b):

$$L_{\text{bol}} = 8 \times L_{14-195} = 8 \times 4\pi d_L^2 \frac{F_{14-195}}{(1+z)^{2-\Gamma}}, \quad (1)$$

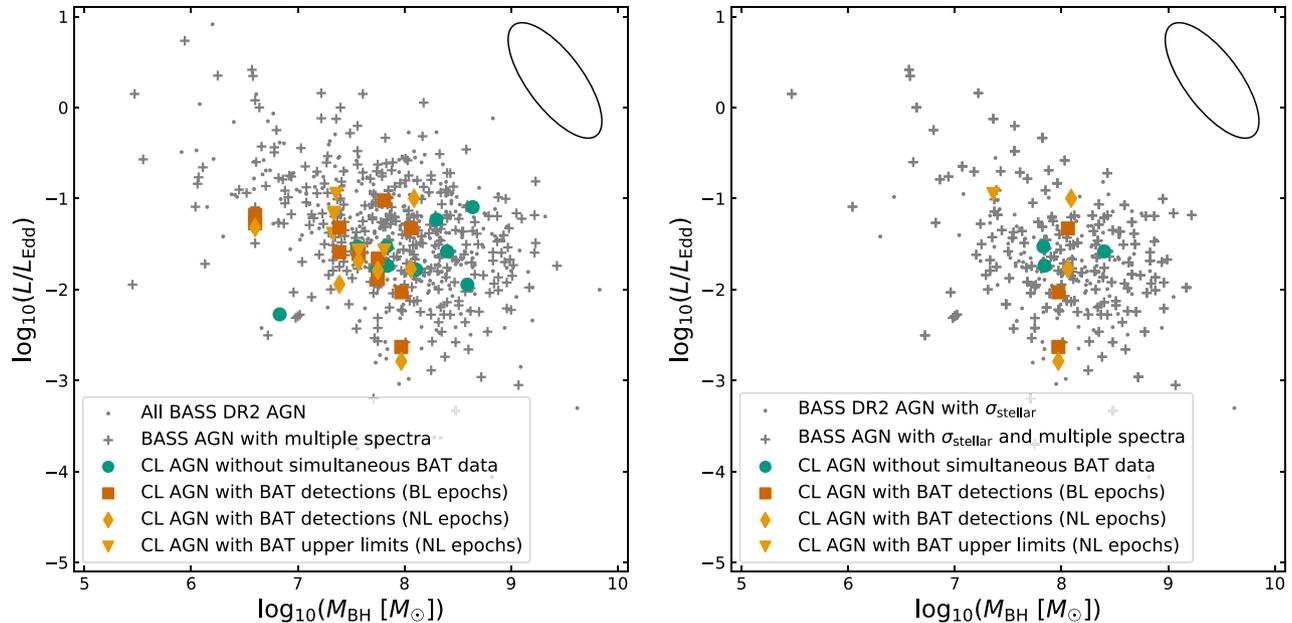


Figure 2. Left-hand panel: 747 unbeamed $z < 0.5$ AGN with black hole mass and Eddington ratio estimates from BASS DR2 (Koss et al. 2022b). Bolometric luminosities are estimated using $L_{\text{bol}} = 15 \times L_{\text{intrinsic } 2-10 \text{ keV}}$ where available from Ricci et al. (2017), else $L_{\text{bol}} = 8 \times L_{14-195 \text{ keV}}$. Right-hand panel: as left, but only including objects with M_{BH} inferred from measurements of the host galaxy stellar velocity dispersion (Koss et al. 2022c). Crosses show objects with multiple epochs of optical spectroscopy which form the parent sample for this work. CL AGN are shown in orange where L/L_{Edd} can be inferred from simultaneous BAT light curves (Section 2.3) with different shapes representing epochs where broad Balmer lines are seen (BL epochs) and epochs where only narrow lines are observed (NL epochs). The green circles show CL AGN where the change in state is not covered by the 157-month *Swift*-BAT survey, and L/L_{Edd} is instead taken from Ricci et al. (2017). The ellipse shows the 1σ covariant uncertainty arising from representative 0.45 dex uncertainties on both M_{BH} and L_{bol} (Koss et al. 2022b). All our CL AGN appear to have $L/L_{\text{Edd}} \lesssim 0.1$, as expected if CL behaviour arises from changes in the accretion disc structure (Noda & Done 2018; Ruan et al. 2019).

where F_{14-195} is the weighted-average 14–195 keV flux from BAT in the 6 months prior to the date of the relevant optical spectrum.

3 RESULTS

CL AGN can be divided into two broad categories (e.g. Ricci & Trakhtenbrot 2022): those due to changes in line-of-sight obscuration, and those due to intrinsic variability such as changes in the structure of the accretion flow or the BLR. Here we discuss each CL AGN individually, with the aim of distinguishing between those which could be ascribed to obscuration, and those which are *bona fide* CS AGN. The ultra-hard X-ray flux measured by *Swift*-BAT is not only probing the power emitted by the accretion disc, but also remains unaffected by changes in obscuration on the level of $N_{\text{H}} \lesssim 10^{24} \text{ cm}^{-2}$ (Ricci et al. 2015; Koss et al. 2016), meaning that any change in the BAT flux contemporaneous with an optical CL event is most likely due to CS transition. We therefore include discussion of the BAT light curves where available for each CL event.

3.1 New CL events

In this section, we present eight newly identified CL events and compare their optical BASS spectra (Table 1 and Fig. 3) with their 14–195 keV light curves from the BAT 157-month catalogue (Fig. 4).

3.1.1 NGC 526A

NGC 526A (BAT 72) was observed as a type 2 source with only narrow Balmer emission lines in 2009 July. In early 2010, an increase was seen in the BAT flux by around a factor of two. In 2016 and 2018,

the source is observed with a broad component in the $H\alpha$ emission line and so we consider it to be a ‘turn-on’ CS AGN, although we note that no corresponding change is detected in $H\beta$.

3.1.2 NGC 1365

We present a newly discovered ‘turn-off’ event in the CL AGN NGC 1365 (BAT 184). NGC 1365 was observed to show broad emission lines in both $H\alpha$ and $H\beta$ in 1993 August (Schulz et al. 1999), but in a spectrum taken in 2009 January Trippe et al. (2010) report only narrow $H\beta$, with any broad $H\alpha$ emission being very weak, suggesting that the source ‘turned off’ between 1993 and 2009. In BASS DR1 we released a 2010 September spectrum which showed no change from 2009 January, with NGC 1365 still displaying only narrow $H\alpha$ and $H\beta$. However, we then see broad Balmer lines in our 2013 December and 2017 June spectra, suggesting that the source has turned back on between 2010 and 2013. Onori et al. (2017) find broad near-infrared Paschen lines in 2011 October observations with ISAAC, suggesting that either the turn-on event happened rapidly between 2011 September and 2011 October, or that the type 2 behaviour observed in the optical in 2009–10 was due to dust obscuration which attenuated the broad Balmer lines (e.g. Goodrich 1995). We note that Lena et al. (2016) found broad $H\alpha$ in 2013 January IFU observations with GMOS, as did Venturi et al. (2018) in 2014 October observations with MUSE, who also found a kiloparsec-scale bi-conical outflow (see also Kakkad et al. 2022). We re-observed this source with Magellan MagE in 2021 December, identifying only narrow $H\alpha$ and $H\beta$, suggesting that the source once again turned off between 2014 October and 2021 December in a newly discovered CL event.

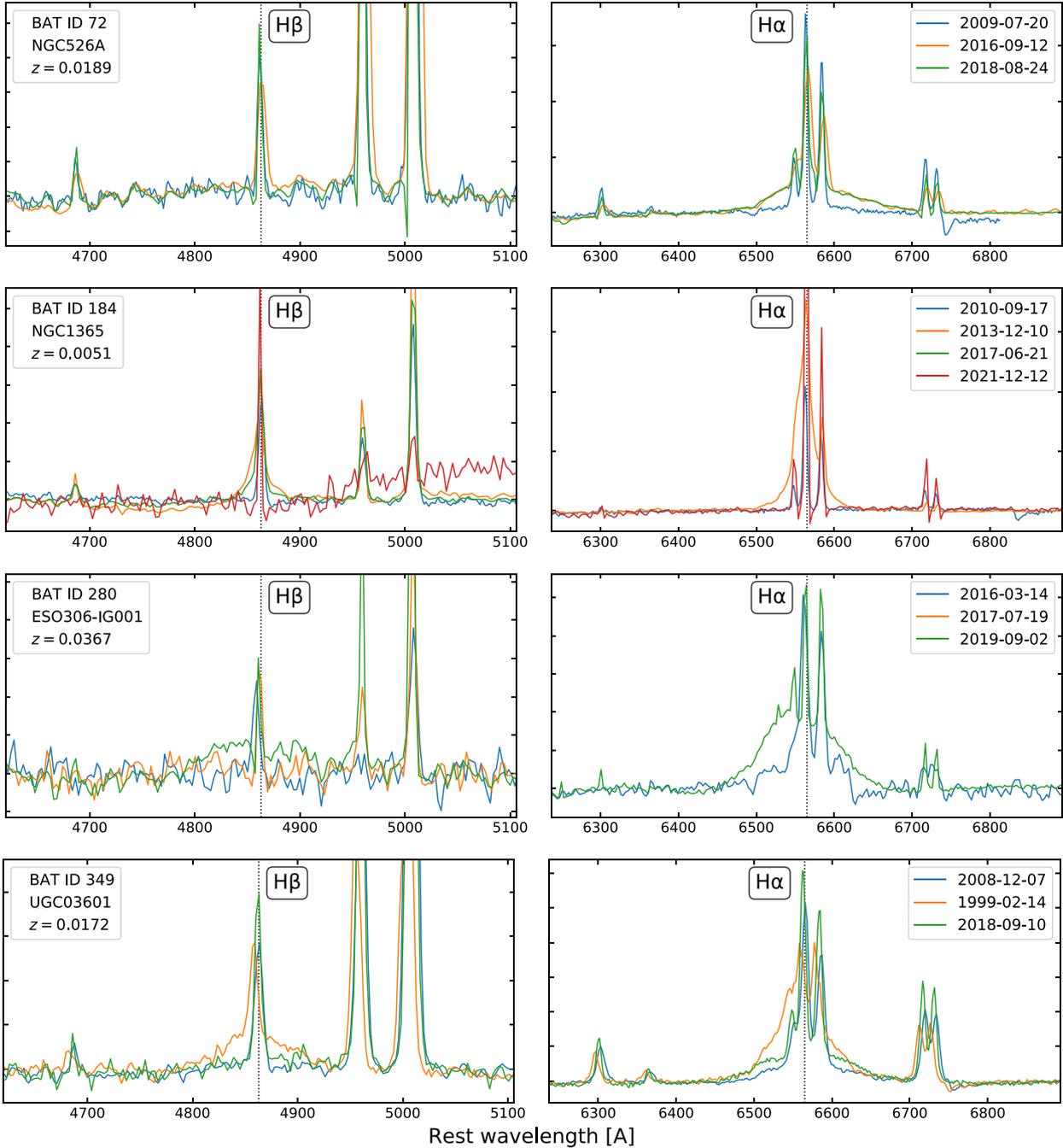


Figure 3. Flux density spectra for BASS AGN with CL events newly identified in this work. Counts have been normalized using the median flux density across the 4500–5200 and 6000–7000 Å spectral windows to allow a direct comparison of the emission line morphologies. The dotted lines show the rest-frame wavelengths of Balmer H β λ 4861 and H α λ 6563.

NGC 1365 is well-known to have previously displayed rapid changes in its X-ray spectral properties, from Compton-thick to Compton-thin and back again within just six weeks in 2002 and 2003. The rapid nature of this change led to its attribution to variable obscuration (Matt et al. 2003; Risaliti et al. 2005; Marin et al. 2013). Further X-ray follow-up found NGC 1365 in a high-flux state with low column absorption in 2013 January (Braitto et al. 2014), although recent work has suggested that the X-ray observations can also be

explained by a variable accretion rate leading to changes in the coronal geometry (Mondal et al. 2022). This variable obscuration may lead to additional uncertainties in the intrinsic luminosity traced by the BAT light curve. Between 2004 and 2013, the flux in the BAT light curve flickers by around a factor of three, although no obvious correlation can be drawn between the changes in the optical classifications and the peaks and troughs in the X-ray light curve.

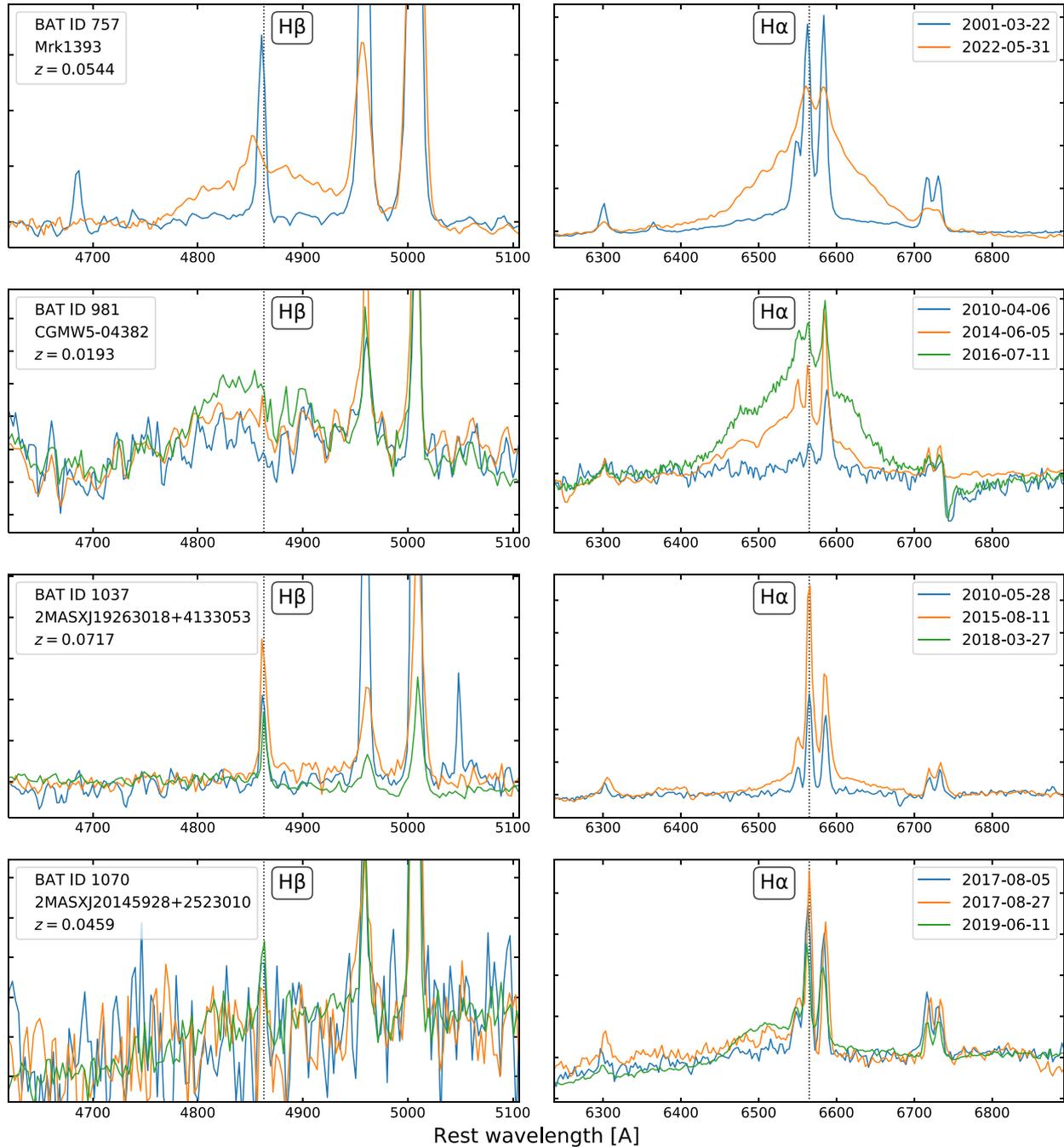


Figure 3. Continued.

3.1.3 ESO 306–IG 001

ESO 306–IG 001 (BAT 280) is an interacting galaxy pair, separated by around 20 arcsec. We have verified that all the spectra used in our analysis are of the southern, active galaxy nucleus, which is clearly identifiable by virtue of its bluer colours in optical imaging and redder colours in *WISE*. In 2019 September, we identified the appearance of broad $H\alpha$ emission which was not present in 2016 March, and moreover the appearance of broad $H\beta$ emission which was not present in 2017 July. The BAT light curve shows tentative evidence for an increase in flux in the second half of 2017, during the last 6 months of currently available data. Future data releases from

Swift-BAT should provide X-ray fluxes covering the period from 2017 to 2019 when the change was observed in the optical spectra.

3.1.4 UGC 03601

UGC 03601 (BAT 349) shows emission from broad $H\alpha$ and $H\beta$ lines in 1999. In 2008 and 2018, emission from broad $H\alpha$ is significantly weaker, and no broad component is visible in $H\beta$. The BAT light curve shows the X-ray flux dropping by a factor of ≈ 3 from 2006 to 2008, and staying at a lower level through to the end of the 157-month survey in 2018.

Table 1. BASS spectra for the eight CL AGN discussed in Section 3.1. ‘B’: broad line observed, ‘N’: no broad line observed, ‘–’: no spectral coverage. ‘Type’ refers to the estimated type classification using the criteria described by Osterbrock (1981).

BAT ID	SWIFT name	Counterpart name	Observation dates	H β	H α	Type	Instruments
BAT 72	SWIFT J0123.8–3504	NGC 526A	2009-07-20	N	N	2	CTIO/RC
			2016-09-12	N	B	1.9	duPont/BC
			2018-08-24	N	B	1.9	VLT/Xshooter
BAT 184	SWIFT J0333.6–3607	NGC 1365	2010-09-17	N	N	2	CTIO/RC
			2013-12-10	B	B	1.5	VLT/Xshooter
			2017-06-21	B	–	–	VLT/FORS2
			2021-12-12	N	N	2	Magellan/MagE
BAT 280	SWIFT J0528.1–3933	ESO 306–IG 001	2016-03-14	N	N	2	duPont/BC
			2017-07-19	N	–	–	VLT/FORS2
			2019-09-02	B	B	1.5	VLT/Xshooter
BAT 349	SWIFT J0655.8+3957	UGC 03601	1999-02-14	B	B	1.5	KPNO/Goldcam
			2008-12-07	N	N	2	KPNO/Goldcam
			2018-09-10	N	B	1.9	Palomar/DBSP
BAT 757	SWIFT J1508.8–0013	Mrk 1393	2001-03-22	N	N	2	APO/SDSS
BAT 981	SWIFT J1830.8+0928	CGMW 5–04382 (LEDA 2808003)	2022-05-31	B	B	1	LCO/FLOYDS
			2010-04-05	N	N	2	Perkins/DeVeny
			2014-06-05	N	B	1.8	VLT/Xshooter
BAT 1037	SWIFT J1926.9+4140	2MASX J19263018+4133053 (LEDA 2182842)	2016-07-11	B	B	1.5	Palomar/DBSP
			2010-05-28	N	N	2	Perkins/DeVeny
			2015-08-11	N	B	1.9	Palomar/DBSP
BAT 1070	SWIFT J2015.2+2526	2MASX J20145928+2523010	2018-03-27	N	–	–	Palomar/DBSP
			2017-08-05	N	N	2	Palomar/DBSP
			2017-08-27	N	N	2	Palomar/DBSP
			2019-06-11	N	B	1.9	Palomar/DBSP

3.1.5 Mrk 1393

Mrk 1393 (BAT 757) was observed to show galaxy-dominated continuum in 1993, 2001, 2005 (Wang et al. 2009), with no broad H β present in the 2001 March spectrum from SDSS, leading to it being classified as a type 1.9 in BASS DR1. However, a 1984 spectrum presented by Morris & Ward (1988) shows broad Balmer emission, suggesting the source turned off between 1984 and 1993. X-ray observations of Mrk 1393 were presented by Wang et al. (2009), who discussed a scenario in which variable obscuration in the optical and X-rays could be due to dusty material disrupted from the circumnuclear torus. Wang et al. (2009) also detected weak broad H β in their 2005 September spectrum, with a line-of-sight extinction of 0.6 mag estimated from the Balmer decrement. A new, previously unpublished spectrum taken in 2022 May with LCO/FLOYDS shows a much brighter and bluer continuum, along with much stronger broad H α and H β emission lines consistent with an unobscured line-of-sight to the BLR. We therefore classify this as a new ‘turn-on’ event which has taken place between 2005 and 2022. Recent photometry from the Zwicky Transient Facility (ZTF; Bellm et al. 2019; Masci et al. 2019) shows a brightening of almost two magnitudes in 2021 in the g and r bands (ZTF18acxctu; AT 2019aahm; Fremling 2020), consistent with the appearance of an AGN-dominated continuum.

3.1.6 CGMW 5-04382

CGMW 5-04382 (LEDA 2808003; BAT 981) shows a brightening of broad line emission in both H α and H β between 2010 April (when it displayed only narrow emission lines) and 2014 June, and again between 2014 June and 2016 July. We therefore classify it as a turn-on CL AGN. X-ray spectral analysis by Ricci et al. (2017) found a column density of $N_{\text{H}} = 10^{23.2}$, suggesting this source was X-ray obscured when the source was observed by *Swift*-XRT in 2007

September. The BAT light curve is noisy with low flux rates, which is consistent with the possibility that the CL transition observed in this source is due to variable obscuration.

3.1.7 2MASX J19263018+4133053

2MASX J19263018+4133053 (LEDA 2182842; BAT 1037) resembled a type 2 AGN in 2010 May, with only narrow H α and H β emission lines present. In 2015 August, a broad base is clearly visible in the H α line, though a corresponding feature is not detected in H β in either 2015 August or 2018 March. 2MASX J19263018+4133053 was detected in 2020 and 2021 as a variable source in optical photometry (ZTF20aazwurf; AT 2020kcu; Forster et al. 2020). The BAT light curve is also noisy with low signal-to-noise ratio even in the rebinned light curve.

3.1.8 2MASX J20145928+2523010

2MASX J20145928+2523010 (BAT 1070) is a Compton-thick ($N_{\text{H}} = 10^{24.2} \text{ cm}^{-2}$) AGN which is also very red ($g-r \approx 2$ mag) in optical imaging. Correspondingly, the signal-to-noise in the H β region of the optical spectra is poor. In 2017 August only narrow H α emission is detected, but in 2019 June a broad emission feature appears around $\lambda_{\text{rest}} = 6510 \text{ \AA}$, which we interpret as broad, albeit blueshifted, H α emission. BAT 1070 was detected as a transient source in ZTF photometry (ZTF19aawrrqy; AT 2019aagk; De 2020), with a 0.7 mag brightening in the r band within 6 months in the second half of 2020 which has since faded.

The BAT light curve showed a peak in the first half of 2007, which subsequently decreased to a low flux state, as observed between 2009 through the end of the 157-month BAT observations in 2017 December. Future data releases from *Swift*-BAT should include X-ray data covering the 2017–2019 period in which the optical transition was observed.

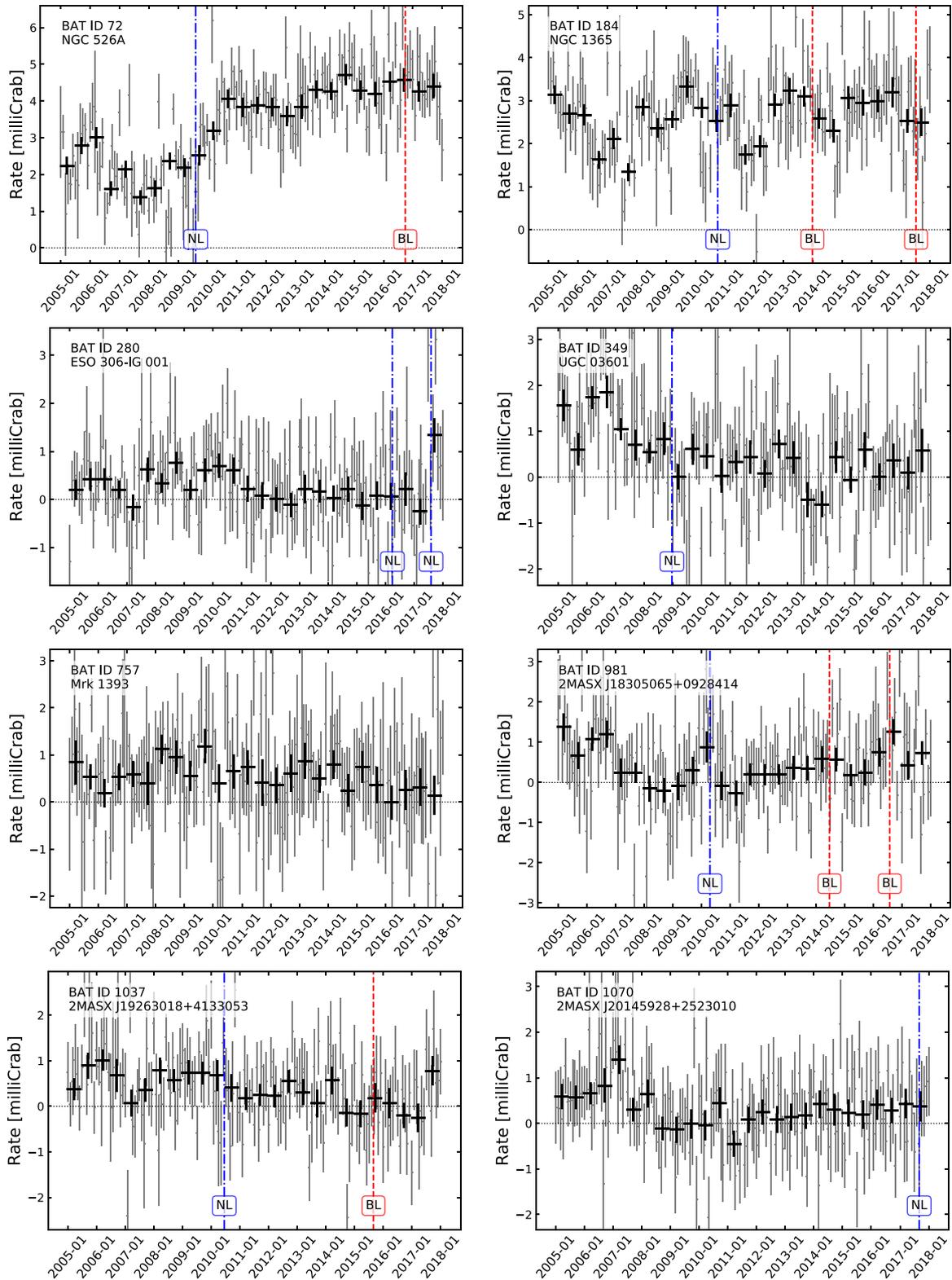


Figure 4. *Swift*-BAT 14–195 keV light curves spanning 2004 December to 2017 December inclusive for the eight CL AGN presented in Section 3.1. Individual months are shown in grey, and rebinned to 6-month intervals in black. Epochs labelled in red as ‘BL’ correspond to the dates of optical spectra in which broad Balmer emission is seen; epochs in blue labelled as ‘NL’ are those where only narrow Balmer lines are seen.

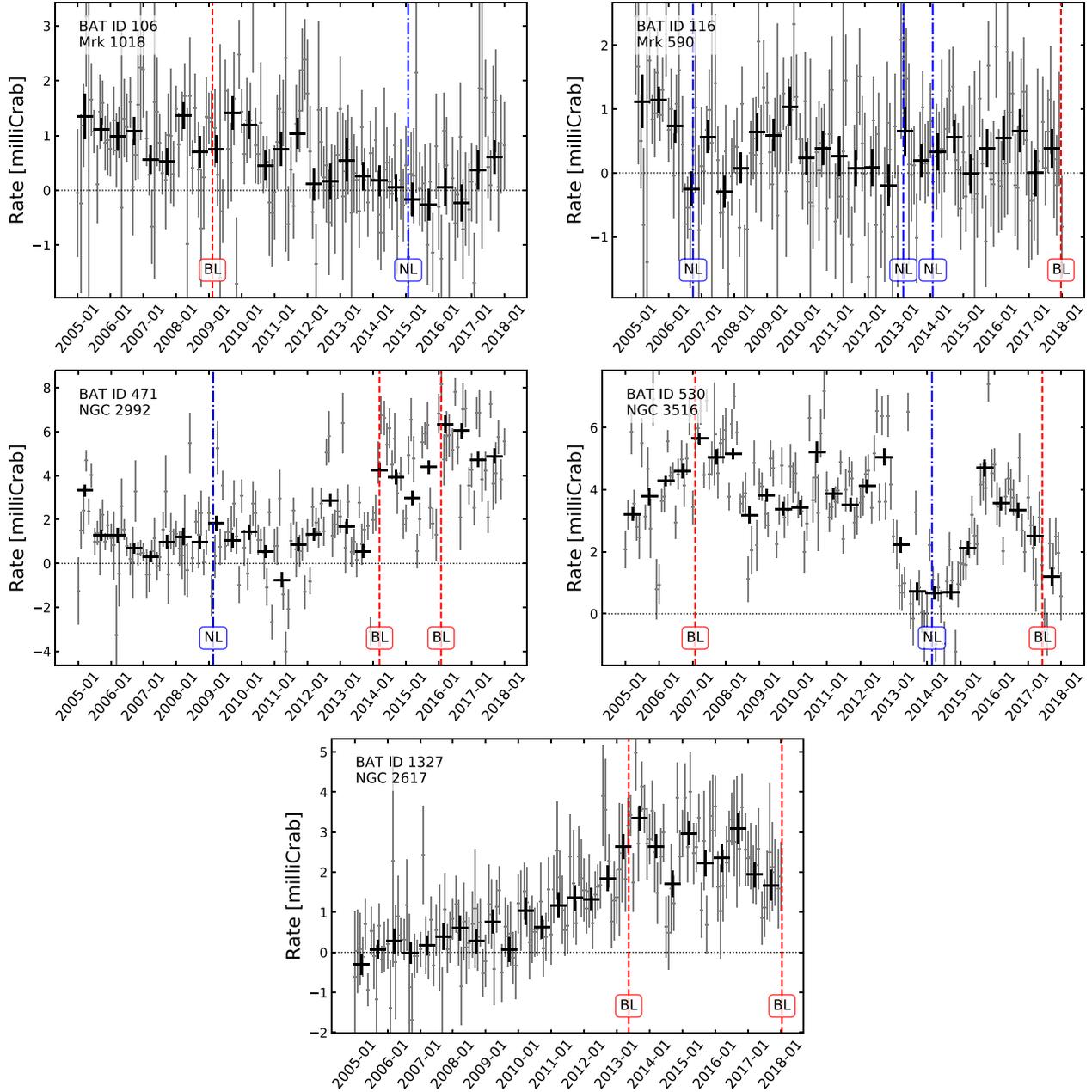


Figure 5. *Swift*-BAT 14–195 keV light curves spanning 2004 December to 2017 December inclusive for the five known CL AGN discussed in Section 3.2. Individual months are shown in grey, and rebinned to 6-month intervals in black. Epochs labelled in red as ‘BL’ correspond to the dates of optical spectra in which broad Balmer emission is seen; epochs in blue labelled as ‘NL’ are those where only narrow Balmer lines are seen.

3.2 Previously known CL events

The BASS catalogue contains some of the most well-known and well-studied AGN in the local universe, including many that had previously been observed to change type. Fairall 9 (BAT 73), NGC 1566 (BAT 216), HE 1136-2304 (BAT 557), KUG 1141+371 (BAT 565), NGC 4151 (BAT 595), 3C 390.3 (BAT 994), NGC 7582 (BAT 1188), NGC 7603 (BAT 1189), and IRAS 23226-3843 (BAT 1194) have all been observed to show CL behaviour (Tohline & Osterbrock 1976; Penston & Perez 1984; Kollatschny & Fricke 1985; Wamsteker et al. 1985; Malkov, Pronik & Sergeev 1997; Aretxaga et al. 1999; Kollatschny, Bischoff & Dietrich 2000; Shapovalova et al. 2008; Parker et al. 2016; Oknyansky et al. 2019; Kollatschny et al. 2020;

Jiang et al. 2021; Liu et al. 2022; Oknyansky 2022). These nine AGN are shown with green circles in Fig. 2.

In this section, we list a further five AGN where a change in state has been identified in the literature, and where these transitions have occurred during the course of the 157-month BAT survey (2004 December to 2017 December). We present 14–195 keV light curves for these objects in Fig. 5.

3.2.1 Mrk 1018

Mrk 1018 (BAT 106) was observed to turn on between 1979 and 1984 (Cohen et al. 1986), and then turn off again between 2009 and 2015

(Husemann et al. 2016; McElroy et al. 2016). In the X-rays, there is a drop in flux from 2009 to 2015 which we associate with the turn-off CS event seen in the optical. Mrk 1018 was observed by SDSS in 2000 September with a type 1 spectrum which was subsequently included in BASS DR1 and DR2.

3.2.2 Mrk 590

Mrk 590 (BAT 116) is a well-known variable AGN and has been extensively studied in multiple wavebands. Between 1996 and 2006, the source transitioned from type 1 to type 2, as reported by Denney et al. (2014), who also showed that broad Balmer emission was not present in 2013 February, 2013 December, or 2014 January. Mathur et al. (2018) reported a subsequent brightening in the ultraviolet continuum and the presence of broad Mg II λ 2800 emission in *Hubble Space Telescope* observations obtained in 2014 November. A BASS DR2 observation with Xshooter in 2017 December clearly show the re-appearance of broad H α and broad H β emission, in agreement with the MUSE observations of Raimundo et al. (2019) who found broad Balmer emission in 2017 October and November. The BAT light curve is noisy and there is no clear transition in the ultra-hard X-ray flux, although recent analysis of X-ray spectra from *NuSTAR* and *Swift*-XRT (Ghosh et al. 2022) shows an increase in the Eddington ratio from 7.5×10^{-3} in 2016 February to 1.9×10^{-2} in 2018 October, around the time the source turned on in the optical spectra.

3.2.3 NGC 2992

NGC 2992 (BAT 471) is an interacting galaxy with a bi-conical ionized gas outflow (Veilleux, Shopbell & Miller 2001; Kakkad et al. 2022) and a rich archive of observations analysed in detail by Guolo et al. (2021). In brief, NGC 2992 was observed to lose its broad H α emission in 1994, and then to have returned by 1999 (Allen et al. 1999; Gilli et al. 2000). These variations were shown to correlate with the X-ray flux: from the high state observed by Mushotzky (1982), the X-ray flux declined to a minimum in 1994, before returning to the original level in 1999 (Gilli et al. 2000). The X-rays were further shown to undergo a changing-obscurtion event by Matt et al. (2003).

A BASS spectrum taken in 2009 January shows no broad H β or H α emission, suggesting that the source had returned to type 2. However, in 2014 February and 2016 January, there is evidence for a broad H α emission component which is not seen in 2009 (see also Caglar et al. 2020). The BAT light curve shows an increase by a factor of ≈ 6 from 2009 through to 2016, which we associate with a further ‘turn-on’ CL event. Near-infrared observations in 2012 January show weak broad (and strong narrow) emission in Paschen β and He I, which might suggest the continuing presence of a BLR that is obscured by dust at optical wavelengths (Onori et al. 2017). However, Guolo et al. (2021) showed that the intrinsic (absorption-corrected) X-ray flux varies by a factor of 40 between 2010 and 2020, and that the broad H α line strength is well-correlated with these variations in the intrinsic luminosity. Guolo et al. (2021) are therefore able to rule out changes in obscuration as an explanation for the recent transitions in the optical spectra of NGC 2992, instead classifying it as a CS AGN.

3.2.4 NGC 3516

NGC 3516 (BAT 530) was observed to change between type 1 in 2007 and type 2 in 2014, with broad H α re-appearing by 2017 (Shapovalova et al. 2019). Our BASS DR1 spectrum from 2009

April shows strong broad lines, meaning that the turn-off event happened between 2009 and 2014. The BAT light curve shows a peak in 2007 which drops significantly to a minimum in 2014, before recovering in 2016. We associate these changes in the X-ray flux with the respective turn-off and turn-on CS events in NGC 3516. Further follow-up observations have been reported by Oknyansky et al. (2021), showing a brightening of broad Balmer line emission through 2020, consistent with the broad lines seen in 2019 June spectrum included in BASS DR2. We refer the interested reader to Oknyansky et al. (2021) for a full discussion of the history of this object.

3.2.5 NGC 2617

NGC 2617 (BAT 1327) was classified as type 1.8 in 2003, and transitioned to type 1 in 2013 (Shappee et al. 2014; Oknyansky et al. 2017). Subsequent follow-up (Oknyansky et al. 2017; Yang et al. 2021) showed the continued presence of broad Balmer line emission through 2016, similar to the type 1 behaviour seen in BASS spectra in 2017 and 2020.

NGC 2617 was not included in BASS DR2 as it was not detected in the 70-month BAT survey (Baumgartner et al. 2013). Fig. 5 shows a strong increase in the 14–195 keV X-ray flux from 2010–2012, and NGC 2617 was detected in the BAT 105-month survey (Oh et al. 2018). Its BAT flux remained high from 2012 through to the end of the 157-month light curve in 2017 December. We therefore associated the increase in X-ray flux in 2010–2012 with the turn-on CS event seen in the optical spectra.

4 DISCUSSION

4.1 Rate of CL events in local AGN

Given the heterogeneity of our parent sample, which takes optical spectra from multiple sources with various different selection functions, it is not possible to draw precise conclusions about the rate of CL events from the sample discussed in this paper. However, we can instead use this population to estimate upper and lower limits on the rate of CL transitions in BASS AGN. The size of our CL sample is small and so the quoted uncertainties in the following discussion are derived assuming Poisson statistics.

From the 749 unique non-beamed $z < 0.5$ AGN in the BAT 70-month catalogue, we know of eight CL AGN where the change in optical type classification occurred between 2004 November and 2017 December: BAT IDs 72, 106, 116, 184, 471, 530, 981, and 1037. This places a robust lower limit of at least 1.1 ± 0.4 per cent of local ($z \approx 0.03$) AGN undergoing changes in state on observed-frame time-scales shorter than 13.1 yr.

Restricting to our parent sample, we have 412 objects where we have temporal coverage such that we might have expected to observe changes in the Balmer lines. Taking the same eight CL objects as above gives a mid-range estimate of 1.9 ± 0.7 per cent of BASS AGN displaying CL behaviour within a 13.1 yr time frame.

Including all archival results from the literature (Section 3.2), 21 BASS AGN are now known to have undergone at least one CL transition over the past 50 yr. This gives a lower limit of at least 2.8 ± 0.6 per cent (21/749) of non-beamed $z < 0.5$ BASS AGN displaying CL behaviour within a 50 yr period. If all 21 of these CL AGN had been found from within the parent sample in this work, we would have derived a rate of 5.1 ± 1.1 per cent (21/412) of local AGN undergoing at least one CL event within ≈ 10 –25 yr time-scales. In

reality this likely represents an overestimate of the rate of CL events in BASS AGN.

These conservative constraints are consistent with the results of López-Navas et al. (2022), who estimate that around 1.8 per cent of type 2 AGN transition to type 1 over the course of 15 yr. However, we note that the uncertainty associated with this measurement remains large, as they extrapolate from spectroscopic follow-up observations of just six of their 30 CL candidates. Similarly, while Runco et al. (2016) reported that 38 per cent of $0.02 < z < 0.1$ Seyfert galaxies show changes in their $H\beta$ flux on 3–9 yr time-scales, only 2.9 ± 1.7 per cent of their sample show the complete disappearance of broad Balmer emission, which is consistent with our results (derived through a similar approach). Hon et al. (2022) also report a CL rate of ≈ 3 per cent per 15 yr, which is consistent with our results. On the other hand, Green et al. (2022) found only 19 CL events from a sample of 64 039 SDSS quasars, giving a rate of ≈ 0.03 per cent across a ≈ 10 yr time-scale, some two orders of magnitude lower than the CL rate which we find in BASS AGN. However, Green et al. (2022) do not claim to be complete, and their initial sample of quasars have much higher Eddington ratios compared to the BASS sample. Such objects are known to be less likely to display CL behaviour (MacLeod et al. 2019), so it is not surprising that Green et al. (2022) find a lower incidence of CL behaviour.

Our inferred rate of ≈ 0.7 – 6.2 per cent per 10–25 yr is significantly higher than those of tidal disruption events, which are predicted to occur of the order of 10^{-4} times per year per galaxy, and are observed even less frequently (Stone & Metzger 2016; Stone et al. 2020; Gezari 2021). Tidal disruption of stars is therefore unlikely to be the main mechanism for our observed CL behaviour.

4.2 Physical drivers of CL behaviour

We have identified nine changes of AGN type which are constrained to have taken place during the 2004 December to 2017 December period of the 157-month BAT survey. This includes two CL events in BAT 530 and one event each in the seven other CL AGN listed in the previous section. Three out of these nine events could be due to variable obscuration: BAT 981 and BAT 1070 have had X-ray column densities measured of $N_{\text{H}} = 10^{23.2}$ and $10^{24.4} \text{ cm}^{-2}$, respectively (Ricci et al. 2017), and BAT 184 is known to have variable X-ray obscuration (Matt et al. 2003; Risaliti et al. 2005; Marin et al. 2013). Five of the six other CL events show clear changes in their BAT light curves, with broad-line epochs (as expected) corresponding to brighter X-ray levels compared with narrow-line epochs. The remaining event was that in BAT 116, which has an inconclusive BAT light curve but otherwise has been shown to undergo significant changes in its intrinsic luminosity (Ghosh et al. 2022). These changes in X-ray luminosity (in six out of nine CL events) would not be expected if the optical changes were solely due to variable Compton-thin obscuration, as the 14–195 keV energy band is less affected by changes in the line-of-sight column.

In general, the column densities from X-ray spectral analysis (Fig. 6) tend to be lower in CL AGN than in the overall population. The median N_{H} is $10^{21.3} \text{ cm}^{-2}$ in the 21 BASS AGN which are now known to be CL AGN, compared to $10^{22.3} \text{ cm}^{-2}$ in our parent sample, consistent with a scenario in which CL AGN are mostly unobscured. Previous work from the BASS collaboration (Koss et al. 2017; Oh et al. 2022) has shown that ≈ 90 per cent of Seyfert type classifications in local AGN agree with their X-ray obscuration. Our results therefore support a scenario in which many of the most extreme changes in observed AGN broad line emission are due to changes in the underlying accretion rate.

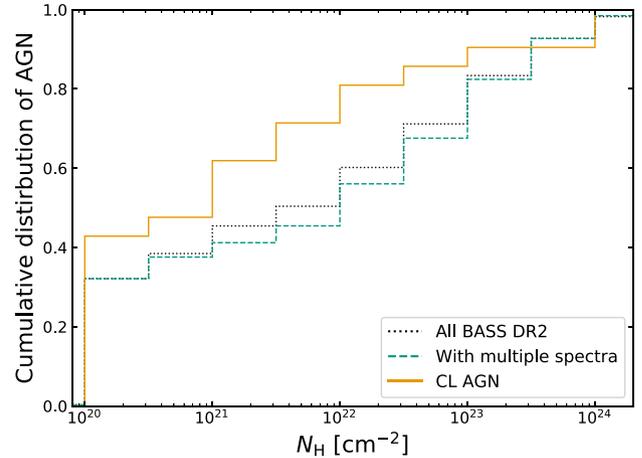


Figure 6. Cumulative distribution of the column densities along the lines of sight to BASS AGN, as measured by Ricci et al. (2017). The CL AGN discussed in this work (solid orange line) tend to prefer lower values of $N_{\text{H}} < 10^{22} \text{ cm}^{-2}$, meaning that they are less likely to be X-ray obscured than a random BASS AGN.

In Fig. 2, we show the distribution of our new CL AGN in the $M_{\text{BH}}-L/L_{\text{Edd}}$ plane. The uncertainty on our estimated L/L_{Edd} includes that associated with the assumption of a constant bolometric correction, which we estimate to be around 0.45 dex following the scatter between $L_{14-195 \text{ keV}}$ and $L_{5100 \text{ \AA}}$ found in BASS DR1 (Koss et al. 2017). With this caveat in mind, we can say that we do not observe a significant number of CL AGN with $L/L_{\text{Edd}} \gtrsim 0.1$. We conducted a Monte Carlo experiment, producing 100 000 random realizations of our CL sample from the parent distribution of L/L_{Edd} . Only 0.37 per cent of these realizations had $L/L_{\text{Edd}} < 0.1$ for every object, suggesting that it is unlikely that our observed lack of high accretion rate CL AGN is due to chance. This is in agreement with the results of MacLeod et al. (2019), who found that CL quasars are observed more often at lower Eddington ratios compared to the SDSS quasar population. By analogy with the accretion state transitions in stellar-mass black hole X-ray binary systems, Noda & Done (2018) and Ruan et al. (2019) have suggested that CS behaviour in AGN could arise due to changes in the structure of the inner accretion disc which occur around a critical value of $L/L_{\text{Edd}} \sim 0.02$. Our observed distribution of L/L_{Edd} is consistent with such mechanisms driving the majority of the CL events we find in BASS AGN.

4.3 Time-scales of CL events

The parent sample used in this work consisted of the non-beamed, $z < 0.5$ AGN with more than one epoch of optical spectroscopy in BASS. This sample is very heterogeneous, with a variety in aperture size, spectral resolution, and spectrophotometric calibration quality. The cadence of the repeat observations in this sample was not chosen to support variability science, and in particular was not optimized to study CL events in any way. Some sources have observations from more than one archival programme, while some sources were chosen for repeat observation due to their having poor signal-to-noise ratio, resolution or calibration in BASS DR1, meaning that the subset of BASS AGN which have multi-epoch spectroscopy could be biased in ways which are hard to quantify. In Fig. 7 we plot the distribution of the rest-frame Δt , the difference in time between the first and last spectral epochs for each AGN in our parent sample, together with the distribution of Δt for each pair of spectra which constrain a CL event. These Δt serve as simple upper limits on the time-scale for the

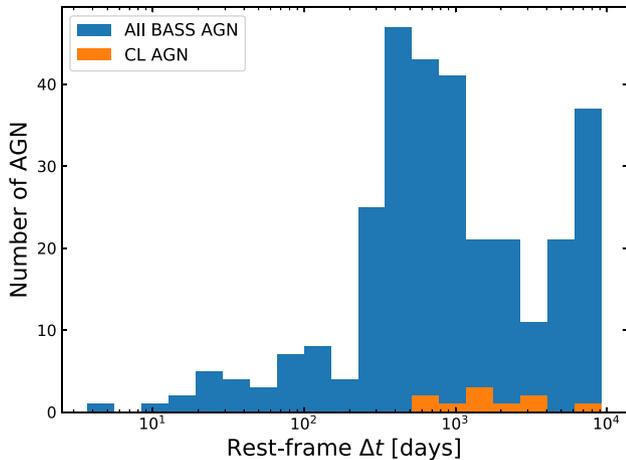


Figure 7. The distribution of Δt , the difference in time between the first and last spectral epochs, in the parent sample, and the CL sample in this work. Using a KS test, we are unable to reject the null hypothesis that our CL events are drawn from the same distribution of Δt as that of our parent sample, with $p = 0.069$. We are therefore limited by the cadence of observations in our parent sample, with most sources having at least one year between spectral epochs.

CL transitions themselves. The parent sample is dominated by time baselines of more than one year, which limits our ability to associate time-scales shorter than ~ 300 d with any CL event. Instead we see that CL transitions are identified over 3–5 yr time-scales, consistent with the distribution of Δt in our parent sample. However, we know that at least some CL transitions occur on much shorter time-scales (e.g. Gezari et al. 2017; Trakhtenbrot et al. 2019; Zeltyn et al. 2022) which we would miss in cases where a source transitions twice (e.g. off and then on again) within ≈ 300 d. Upcoming surveys such as SDSS-V Black Hole Mapper (Kollmeier et al. 2017) will provide better constraints for a much larger sample of CL AGN, probing time-scales from days to years. Our work shows that continued high-cadence spectroscopic monitoring of the BASS sample would be valuable to place better constraints on the variability time-scales in the local AGN population.

4.4 Future work

Future work will involve analysing follow-up observations to characterize how the X-ray spectral properties have changed for the CL sources identified in this work. Broad-band (0.3–195 keV) X-ray spectral fitting has previously been carried out for all BAT AGN (Ricci et al. 2017), but this analysis assumed that there was no variability between the various epochs in which the broad-band X-ray data were obtained. A more sophisticated analysis will look to confirm whether the CL events we have found (especially those for which we do not have BAT light curves) are associated with changes in the intrinsic X-ray luminosity or spectral index.

Many of the CL AGN presented herein also have light curves available from wide-field, multi-epoch imaging surveys, both in the optical (e.g. ZTF) and the IR (*WISE*; Wright et al. 2010). While these data sets generally do not span the same temporal baseline as the BAT light curves presented above, further data collection is ongoing and will be valuable when seeking to understand more recent changes in the BAT AGN sample. Understanding the optical light curves of the complete sample of BAT-selected AGN will further help to select and

classify variable AGN in future surveys such as the Vera C. Rubin Observatory LSST (Ivezić et al. 2019).

5 CONCLUSIONS

We have identified eight new ‘changing-look’ events in low-redshift AGN, using spectra from the combined first and second data releases of BASS. We have focused on the most dramatic spectral transitions, where broad Balmer lines completely appear or disappear between different epochs. By combining with BASS AGN which were previously known to display CL behaviour, we constructed a sample of nine CL events where the change in optical type classification has occurred during the first 157 months of *Swift*-BAT operations (2004 December to 2017 December) and hence for which ultra-hard X-ray light curves are available. Of these nine spectral transitions, five display clear simultaneous changes in their ultra-hard X-ray flux from BAT. This is consistent with a scenario where changes in the accretion disc are driving the changes seen in the optical type, as changing obscuration would need to be Compton-thick in every case to explain the extent of the changes seen in the ultra-hard X-ray emission.

The ultra-hard X-ray selection with *Swift*-BAT which was used to define the BASS sample should be less biased to the optical emission properties, leading to a parent sample which is less biased towards any particular sub-class of CL behaviour. However, the subset of BASS AGN with repeat spectra which was used as the basis of this investigation includes observations from archival programmes which were selected through other criteria. These observations are heterogeneous with a range of aperture effects and different calibration processes. Notwithstanding these limitations, we infer a CL event rate of 0.7–6.2 per cent over ≈ 15 yr time-scales in local AGN, consistent with recent work in the literature.

The BASS DR2 is a comprehensive, multiwavelength effort to understand the properties of a complete sample of low-redshift AGN, making the BAT AGN sample an ideal test-bed to better understand the physics of highly variable and changing-look AGN.

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DATA AVAILABILITY

The optical spectra presented in this article will be made available from the BASS website¹ as part of BASS data releases. The *Swift*-BAT light curves presented in this article will be available from a forthcoming publication led by A. Lien.

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APPENDIX A: VISUAL INSPECTION

In this appendix, we discuss examples of BASS AGN from our parent sample with multiple epochs of spectroscopy which were not identified as CL AGN in our visual inspection process. The instruments used to obtain these spectra are given in Table A1.

The vast majority of our parent sample are consistent with no intrinsic changes in their spectral features. Some small fraction of these show apparent changes in their emission line strengths which could be due to different instrumental resolutions, aperture sizes, or flux calibration procedures. We show three of the clearest examples of such effects in Fig. A1. There are also a small number of objects

Table A1. Summary of the BASS spectra for the seven objects discussed in Appendix A.

BAT ID	Counterpart name	Observation dates	Instruments
BAT 135	ESO 416 – G 002	2001-11-21 2017-06-24 2021-12-12	AAO/6dF VLT/Xshooter Magellan/MagE
BAT 150	2MASX J02502722+4647295	2011-06-01 2018-09-09 2019-08-29	Perkins/DeVeny Palomar/DBSP Palomar/DBSP
BAT 155	LEDA 90641	2011-09-29 2017-08-31	SPM/BC Palomar/DBSP
BAT 235	1RXS J044154.5–082639	1994-06-10 2020-11-12	MPG/EFOSC2 Palomar/DBSP
BAT 301	ESO 424 – 12	2008-12-03 2013-11-23 2013-12-11	SPM/BC VLT/Xshooter VLT/Xshooter
BAT 607	NGC 4235	2005-01-16 2015-05-13	APO/SDSS VLT/Xshooter
BAT 862	SDSS J170859.13+215308.1	2004-06-21 2020-10-23	APO/SDSS Palomar/DBSP

where the strength of the broad Balmer emission line appears to change, and we show three examples in Fig. A2. As discussed in the main text, we only include objects which show the complete appearance or disappearance of a broad line in our CL AGN sample, where it is much more likely that the observed change in the line properties is not due to instrumental effects.

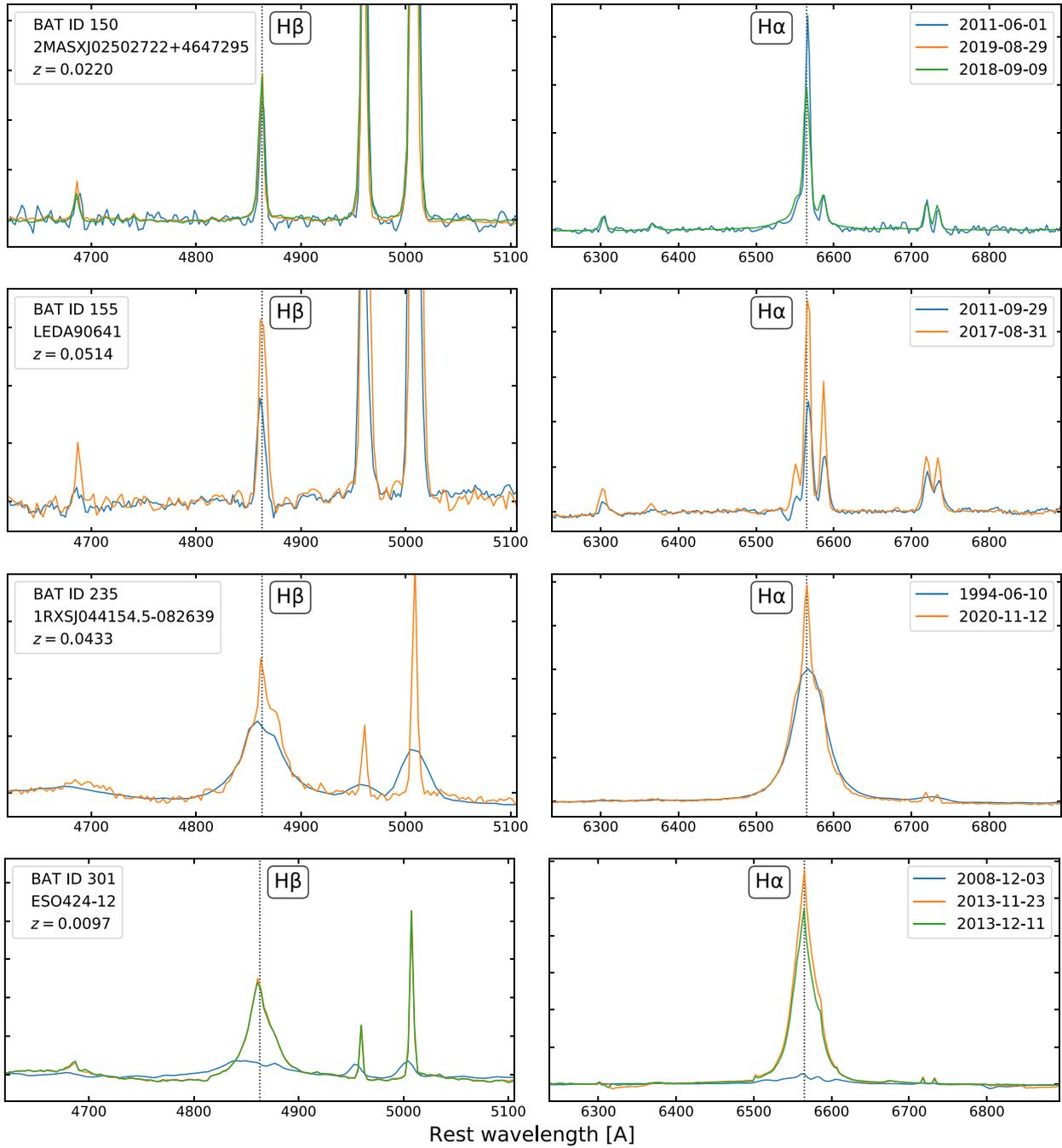


Figure A1. Example flux density spectra for BASS AGN which do not show conclusive evidence for changes in their Balmer emission. The majority of our parent sample, like BAT 150 in the top panel, show no change in their apparent emission line properties. Below we show examples where apparent changes in the Balmer line strengths could be explained by aperture effects (BAT 155), varying spectral resolution (BAT 235), or a combination of both (BAT 301). Such objects were also removed as CL AGN candidates during visual inspection. As in Fig. 3, counts have been normalized using the median flux density across each spectral window and dotted lines show the rest-frame wavelengths of Balmer H β λ 4861 and H α λ 6563.

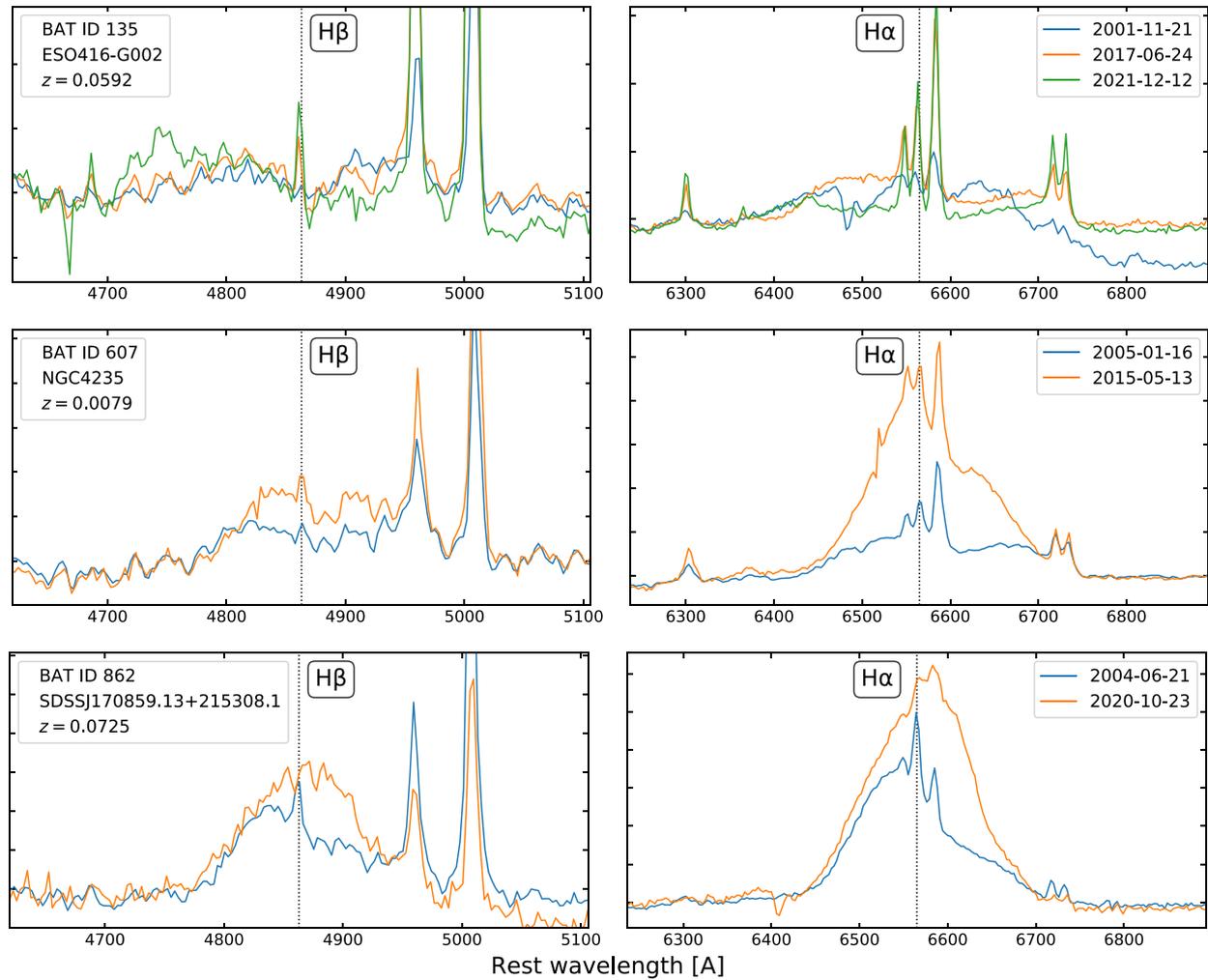


Figure A2. Flux density spectra for three BASS AGN which show evidence for changing Balmer emission morphologies, but which are not included in our final CL sample. BAT 135 appears to show dramatic change between 2001 and 2017, but the 2001 November spectrum is from the 6dF Galaxy Survey and has somewhat uncertain flux calibration (Jones et al. 2004), especially around $H\alpha$ in the red end of the spectrograph. The 2017 June and 2021 December spectra from BASS both show evidence for a very broad, albeit weak, base to the $H\alpha$ emission. BAT 607 and BAT 862 show changes in the strength and velocity structure of their Balmer emission, but broad $H\alpha$ and $H\beta$ are present in all epochs and so these objects do not meet our CL criteria for a complete appearance or disappearance of broad line emission. As in Fig. 3, counts have been normalized using the median flux density across each spectral window and dotted lines show the rest-frame wavelengths of Balmer $H\beta$ $\lambda 4861$ and $H\alpha$ $\lambda 6563$.

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