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

Matthew J. Temple,1* Claudio Ricci,1,2 Michael J. Koss,3,4 Benny Trakhtenbrot,5 Franz E. Bauer,6,7,4 Richard Mushotzky,8 Alejandro F. Rojas,9,1 Turgay Caglar,10 Fiona Harrison,11 Kyuseok Oh,12,13 Estefanía Padilla González,14,15 Meredith C. Powell,16 Federica Ricci,17,18 Rogério Riffel,19 Daniel Stern,20 and C. Megan Urry21

1Núcleo de Astronomía de la Facultad de Ingeniería, Universidad Diego Portales, Av. Ejército Libertador 441, Santiago 22, Chile
2Kavli Institute for Astronomy and Astrophysics, Peking University, Beijing 100871, People’s Republic of China
3Eureka Scientific, 2452 Delmer Street Suite 100, Oakland, CA 94602-3017, USA
4Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, Colorado 80301, USA
5School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel
6Instituto de Astrofísica y Centro de Astroingeniería, Facultad de Física, Pontificia Universidad Católica de Chile, Casilla 306, Santiago 22, Chile
7Millennium Institute of Astrophysics (MAS), Nuncio Monseñor Sótero Sanz 100, Providencia, Santiago, Chile
8Department of Astronomy, University of Maryland, College Park, MD 20742, USA
9Centro de Astronomía (CITEVA), Universidad de Antofagasta, Avenida Angamos 601, Antofagasta, Chile
10Leiden Observatory, P.O. Box 9513, 2300 RA, Leiden, The Netherlands
11Cahill Center for Astronomy and Astrophysics, California Institute of Technology, Pasadena, CA 91125, USA
12Korea Astronomy and Space Science Institute, Daedeokdae-ro 776, Yuseong-gu, Daejeon 34055, Republic of Korea
13Department of Astronomy, Kyoto University, Kitashirakawa-Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan
14Las Cumbres Observatory, 6740 Cortona Drive, Suite 102, Goleta, CA 93117-5575, USA
15Department of Physics, University of California, Santa Barbara, CA 93106-9530, USA
16Kavli Institute of Particle Astrophysics and Cosmology, Stanford University, 452 Lomita Mall, Stanford, CA 94305, USA
17Dipartimento di Matematica e Fisica, Università Roma Tre, via della Vasca Navale 84, I-00146, Roma, Italy
18INAF- Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via Gobetti 93/3, 40129 Bologna, Italy
19Departamento de Astronomía, Instituto de Física, Universidade Federal do Rio Grande do Sul, CP 15051, 91501-970, Porto Alegre, RS, Brazil
20Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, MS 169-224, Pasadena, CA 91109, USA
21Yale Center for Astronomy & Astrophysics and Department of Physics, Yale University, P.O. Box 208120, New Haven, CT 06520-8120, USA

Accepted 2022 November 08. Received 2022 November 02; in original form 2022 September 08

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 year time-scales, and show that many transitions happen within at most a few years. Our results motivate further multi-wavelength 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 have been seen to rapidly change between different Seyfert spectral type class-
ifications: 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 et al. 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-Nava 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 et al. 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 what 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 of 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 multi-wavelength 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 et al. 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 multi-wavelength 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 (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 December 2004. The BAT AGN Spectroscopic Survey (BASS; Koss et al. 2022a) is a comprehensive, multi-wavelength 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 we have 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 $\Omega_M = 0.7, \Omega_r = 0.3, H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, 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 catalogs (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 $\approx 8000–9000\AA$, 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 have redshifts $z > 0.5$, where their observed-frame optical spectra cover the rest-frame ultraviolet
2.2 BAT light-curves

While the AGN in BASS DR2 were selected from the first 70 months of the BAT survey, data is now available covering the first 157 months of Swift operations, from 2004 December to 2017 December (Lien et al. in prep.). We rebinned 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 programs) 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 ($M_{\text{BH}}$) 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. $M_{\text{BH}}$ 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 virialised 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 $\sigma_*$-derived $M_{\text{BH}}$. 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 et al. (2022) showed that the virial $M_{\text{BH}}$ estimated from the bright epochs in a sample of 26 CL AGN is consistent with the $M_{\text{BH}}$ 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 $M_{\text{BH}}$ are still applicable in CL AGN. The dominant uncertainty on each $M_{\text{BH}}$ estimate is of order 0.45 dex due to the systematic uncertainties in virial and $\sigma_*$ 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 $L_{\text{bol}}$. For spectra taken between 2005 and 2017 (inclusive) we infer an estimate of $L_{\text{bol}}$ using the relevant Swift-BAT 14–195 keV light-curve, assuming 1 Crab is 2.3343$\times$10$^{-8}$ erg cm$^{-2}$ 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):

\[
L_{\text{bol}} = 8 \times 10^{41} \text{erg s}^{-1} = 8 \times 4\pi d_{z}^{2} \frac{F_{14-195}}{(1+z)^{2}} \approx 10^{44} \text{erg s}^{-1},
\]

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 \( N_H \lesssim 10^{24} \text{ cm}^{-2} \) (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 Tripple et al. (2010) report only narrow \( H_\beta \), with any broad \( H_\beta \) 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 kilo-parsec-scale bi-conical outflow (see also Kakad 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.

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 vari-
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 | Hβ | Hα | Type | Instruments |
|--------|------------|-----------------|------------------|-----|-----|------|-------------|
| BAT 72 | SWIFTJ0123.8–3504 | 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 | SWIFTJ0333.6–3607 | 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 | SWIFTJ0528.1–3933 | ESO 306–IG001 | 2016-03-14 | N | N | 2 | duPont/BC |
|        |            |                 | 2017-07-19 | B | B | 1.5 | VLT/Xshooter |
| BAT 349 | SWIFTJ0655.8+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 | SWIFTJ1508.8–0013 | Mrk 1393 | 2001-03-22 | N | N | 2 | APO/SDSS |
|        |            |                 | 2022-05-31 | B | B | 1 | LCO/FLOYDS |
| BAT 981 | SWIFTJ1830.8+0928 | CGMW 5–04382 (LEDA 2808003) | 2010-04-05 | N | N | 2 | Perkins/DeVeny |
|        |            |                 | 2014-06-05 | N | B | 1.8 | VLT/Xshooter |
|        |            |                 | 2016-07-11 | B | B | 1.5 | Palomar/DBSP |
| BAT 1037 | SWIFTJ1926.9+4140 | 2MASX J19263018+4133053 (LEDA 2182842) | 2010-05-28 | N | N | 2 | Perkins/DeVeny |
|        |            |                 | 2015-08-11 | N | B | 1.9 | Palomar/DBSP |
|        |            |                 | 2018-03-27 | N | - | - | Palomar/DBSP |
| BAT 1070 | SWIFTJ2015.2+2526 | 2MASX J20145928+2523010 | 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 |

able 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 (Braito 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.

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 Hα emission which was not present in 2016 March, and moreover the appearance of broad Hβ 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 Hα and Hβ lines in 1999. In 2008 and 2018, emission from broad Hα is significantly weaker, and no broad component is visible in Hβ. 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.

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 Hβ 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 Hβ 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 Hα and Hβ 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. 2020).
et al. 2019) shows a brightening of almost two magnitudes in 2021 in the g and r bands (ZTF18acxcttu; AT 2019aahn; Fremling 2020), consistent with the appearance of an AGN-dominated continuum.

3.1.6 CGMW5-04382

CGMW 5-04382 (LEDA 2808003; BAT 981) shows a brightening of broad line emission in both Hα and Hβ 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 $N_H = 10^{23.2}$, 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 2MASXJ19263018+4133053

2MASXJ19263018+4133053 (LEDA 2182842; BAT 1037) resembled a type 2 AGN in 2010 May, with only narrow Hα and Hβ emission lines present. In 2015 August, a broad base is clearly visible in the Hα line, though a corresponding feature is not detected in Hβ in either 2015 August or 2018 March. 2MASXJ19263018+4133053 was detected in 2020 and 2021 as a variable source in optical photometry (ZTF20aazwurf; AT2020kcu; 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 2MASXJ20145928+2523010

2MASXJ20145928+2523010 (BAT 1070) is a Compton-thick ($N_H = 10^{24.2} \text{cm}^{-2}$) AGN which is also very red ($g-r \approx 2$ mag) in optical imaging. Correspondingly, the signal-to-noise in the Hβ region of the optical spectra is poor. In 2017 August only narrow Hα emission is detected, but in 2019 June a broad emission feature appears around $\lambda_{\text{rest}} = 6510$ Å, which we interpret as broad, albeit blueshifted, Hα emission. BAT 1070 was detected as a transient source in ZTF photometry (ZTF19aawrrqy; AT2019aagk; De...
Figure 4. Swift-BAT 14–195 keV light-curves spanning December 2004 to December 2017 inclusive for the eight CL AGN presented in Section 3.1. Individual months are shown in gray, 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.
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 December 2017. Future data releases from Swift-BAT should include X-ray data covering the 2017-2019 period in which the optical transition was observed.

### 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 (BAT73), NGC 1566 (BAT216), HE 1136-2304 (BAT557), KUG 1141+371 (BAT565), NGC 4151 (BAT595), 3C 390.3 (BAT994), NGC 7582 (BAT1188), NGC 7603 (BAT1189) and IRAS 23226-3843 (BAT1194) have all been observed to show CL behaviour (Tohline & Osterbrock 1976; Penston & Perez 1984; Kollatschny & Fricke 1985; Wamsteker et al. 1985; Malkov et al. 1997; Aretxaga et al. 1999; Kollatschny et al. 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;
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 (McElroy et al. 2016; Husemann 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 the 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 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 Hα and broad Hβ 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 et al. 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 Hα 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-obscuration event by Matt et al. (2003).

A BASS spectrum taken in 2009 January shows no broad Hβ or Hα emission, suggesting that the source had returned to type 2. However, in 2014 February and 2016 January, there is evidence for a broad Hα 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 Hα 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 Hα 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 followup (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 December 2017. 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 November 2004 and December 2017: 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 ≈ 0.03) AGN undergoing changes in state on observed-frame time-scales shorter than 13.1 years.

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 $1.9 \pm 0.7$ per cent of BASS AGN displaying CL behaviour within a 13.1 year 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 years. This gives a lower limit of at least $2.8 \pm 0.6$ per cent (21/749) of non-beamed $z < 0.5$ BASS AGN displaying CL behaviour within a 50 year 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 $5.1 \pm 1.1$ per cent (21/412) of local AGN undergoing at least one CL event within $\approx 10$–25 year timescales. In reality this likely represents an over-estimate 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 years. 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 Hβ flux on 3–9 year timescales, only $2.9 \pm 1.7$ 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 $\approx 3$ per cent per 15 years, 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 $\approx 0.03$ per cent across a $\approx 10$ year 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 $\approx 0.7$–6.2 per cent per 10–25 years is significantly higher than those of tidal disruption events, which are predicted to occur of order $10^{-4}$ 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 $N_H = 10^{23.2}$ and $10^{24.4}$ 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 $10^{21.3}$ cm$^{-2}$ in the 21 BASS AGN which are now known to be CL AGN, compared to $10^{22.3}$ 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 $\geq 90$ 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.

In Fig. 2 we show the distribution of our new CL AGN in the $M_{\text{BH}}$–$L_{\text{Edd}}$ plane. The uncertainty on our estimated $L_{\text{Edd}}$ 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 $L_{5100\text{Å}}$ 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 $L/L_{\text{Edd}} \geq 0.1$. We conducted a Monte Carlo experiment, producing 100 000 random re-allocations of our CL sample from the parent distribution of $L/L_{\text{Edd}}$: Only 0.37 per cent of these re-allocations 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 $L/L_{\text{Edd}}$ 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 optimised 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 $\Delta t$, the difference in time between the first and last spectral epochs for each AGN in our parent sample, together with the distribution of $\Delta t$ for each pair of spectra which constrain a CL event. These $\Delta t$ serve as simple upper limits on the time-scale for the 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 $\sim 300$ days with any CL event. Instead we see that CL transitions are identified over 3-5 year time-scales, consistent with the distribution of $\Delta t$ in our parent sample. However, we know that at least some CL transitions occur on much shorter timescales (e.g. Gezari et al. 2017; Trakhtenbrot et al. 2019; Zelty et al. 2022) which would be missed in cases where a source transitions twice (e.g. off and then on again) within $\sim 300$ days. 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 characterise how the X-ray spectral properties have changed for the CL sources identified in this work. Broadband (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 broadband X-ray data was 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 accreditation 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 $\sim 15$ year time-scales in local AGN, consistent with recent work in the literature.

The BASS DR2 is a comprehensive, multi-wavelength 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.

### ACKNOWLEDGEMENTS

We thank the anonymous referee for a constructive report. MJT acknowledges support from CONICYT (Fondo ALMA 31190036) and a FONDECYT fellowship (Proyecto 3220516). CR acknowledges support from FONDECYT (Iniciacion grant 11190831) and ANID BASAL project FB210003. MJT acknowledges support from NASA (ADAP award NNH16CT03C). BT acknowledges support from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation program (grant agreement 950533).
and from the Israel Science Foundation (grant 1849/19). FEB acknowledges support from the ANID Millennium Science Initiative Program (ICN12_009), CATA-BASAL (ACE21000 and FB210003) and FONDECYT Regular (1190181 and 1200495). AFR acknowledges support from FONDECYT Postdoctorado Proyecto 320157. KO acknowledges support from the Korea Astronomy and Space Science Institute under the R&D program (Project No. 2022-1-868-04) supervised by the Ministry of Science and ICT and from the National Research Foundation of Korea (NRF-2020R1C1C1005462). FR acknowledges support from PRIN MIUR 2017PH3WAT (‘Black hole winds and the baryon life cycle of galaxies’). RR thanks Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Proj. 311223/2020-6, 304927/2017-1 and 400352/2016-8), Fundação de Amparo à Pesquisa do Rio Grande do Sul (FAPERGS, Proj. 16/2551-0000251-7 and 19/1795-2), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Proj. 0001).

This research has made use of the NASA/IPAC Extragalactic Database (NED), which is funded by the National Aeronautics and Space Administration and operated by the California Institute of Technology.

**DATA AVAILABILITY**

The optical spectra presented in this article will be made available from the BASS website 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.

**REFERENCES**

Allen M. G., Dopita M. A., Tsvetanov Z. I., Sutherland R. S., 1999, ApJ, 511, 686
Antonucci R., 1993, ARA&A, 31, 473
Aretxaga I., Joguet B., Kunth D., Melnick J., Terlevich R. J., 1999, ApJ, 519, L123
Barthelmy S. D., et al., 2005, Space Sci. Rev., 120, 143
Baumgartner W. H., Buil J., Markwardt C. B., Skinner G. K., Barthelmy S., Mushotzky R. F., Evans P. A., Gehrels N., 2013, ApJS, 207, 19
Bellm E. C., et al., 2019, PASP, 131, 018002
Braito V., Reeves J. N., Gofford J., Nardini E., Porquet D., Risaliti G., 2014, ApJ, 795, 87
den Brok J. S., et al., 2022, ApJS, 261, 7
Caglar T., et al., 2020, A&A, 634, A114
Cohen R. D., Rudy R. J., Puetter R. C., Ake T. B., Foltz C. B., 1986, ApJ, 305, 135
Collin-Souffrin S., Alloin D., Andrillat Y., 1973, A&A, 22, 343
Collin-Souffrin S., Alloin D., Andrillat Y., 1973, A&A, 22, 343
De K., 2020, Transient Name Server Discovery Report, 2020-3485, 1
Forster F., et al., 2020, Transient Name Server Discovery Report, 2020-1365, 1
Fremling C., 2020, Transient Name Server Discovery Report, 2020-3602, 1
Graham M. J., et al., 2020, MNRAS, 491, 4925
Green P. J., et al., 2022, ApJ, 933, 180
Guainazzi M., 2002, MNRAS, 329, L13
Guo H., et al., 2020, ApJ, 905, 52
Guo L., Ruschel-Dutra D., Grupe D., Peterson B. M., Storchi-Bergmann T., Schimoia J., Nemmen R., Robinson A., 2021, MNRAS, 508, 144
Hon W. J., Wolf C., Onken C. A., Webster R., Achett K., 2022, MNRAS, 511, 54
Husemann B., et al., 2016, A&A, 593, L9
Ivezic Z., et al., 2019, ApJ, 873, 111
Jiang J., et al., 2021, MNRAS, 501, 916
Jia J.-X., Wu X.-B., Feng X.-T., 2022, ApJ, 926, 184
Jones D. H., et al., 2004, MNRAS, 355, 747
Kakkad D., et al., 2022, MNRAS, 511, 2105
Kollatschny W., Fricke K. J., 1985, A&A, 146, L11
Kollatschny W., Bischoff K., Dietrich M., 2000, A&A, 361, 901
Kollatschny W., et al., 2020, A&A, 638, A91
Kollmeier J. A., et al., 2017, arXiv e-prints, p. arXiv:1711.03234
Kormendy J., Ho L. C., 2013, ARA&A, 51, 511
Koss M. J., et al., 2016, ApJ, 825, 85
Koss M. J., et al., 2017, ApJ, 850, 74
Koss M. J., et al., 2022a, ApJS, 261, 1
Koss M. J., et al., 2022b, ApJS, 261, 2
Koss M. J., et al., 2022c, ApJS, 261, 6
LaMassa S. M., et al., 2015, ApJ, 800, 144
Lena D., Robinson A., Storchi-Bergmann T., Couto G. S., Schnorr-Müller A., Riffel R. A., 2016, MNRAS, 459, 4485
Liu H., Wu Q., Lyu B., 2022, ApJ, 930, 46
López-Navas E., et al., 2022, MNRAS, 513, L57
Lyu B., Yan Z., Yu W., Wu Q., 2021, MNRAS, 506, 4188
MacLeod C. L., et al., 2019, ApJ, 874, 8
Malkov Y. F., Pronik V. I., Sergeev S. G., 1997, A&A, 324, 904
Marchese E., Braito V., Della Ceca R., Caccianiga A., Severgnini P., 2012, MNRAS, 421, 1803
Marcotulli L., et al., 2020, ApJ, 940, 77
Marin F., Porquet D., Goosmann R. W., Dovciak M., Muleri F., Grossu N., Karas V., 2013, MNRAS, 436, 1615
Masci F. J., et al., 2019, PASP, 131, 018003
Mathur S., et al., 2018, ApJ, 866, 123
Matt G., Guainazzi M., Maiolino R., 2003, MNRAS, 342, 422
McElroy R. E., et al., 2016, A&A, 593, L8
Mejía-Restrepo J. E., et al., 2022, ApJS, 261, 5
Mondal S., Adhikari T. P., Hryniewicz K., Stalin C. S., Pandey A., 2022, A&A, 662, A77
Morris S. L., Ward M. J., 1998, MNRAS, 230, 639
Mushotzky R. F., 1982, ApJ, 256, 92
Narayan R., Yi I., 1995, ApJ, 452, 710
Noda H., Done C., 2018, MNRAS, 480, 3898
Oh K., et al., 2018, ApJS, 235, 4
Oknyansky V. L., et al., 2022, Astronomische Nachrichten, 343, e210080
Oknyansky V. L., et al., 2017, MNRAS, 467, 1496
Oknyansky V. L., Winkler H., Tsygankov S. S., Lipunov V. M., Gorboskov E. S., van Wyk F., Buckley D. A. H., Tyurina N. V., 2019, MNRAS, 483, 558
Oknyansky V. L., et al., 2021, MNRAS, 505, 1029
Onori F., et al., 2017, MNRAS, 464, 1783
Osterbrock D. E., 1981, ApJ, 249, 462
Paliya V. S., et al., 2019, ApJ, 881, 154
Parker M. L., et al., 2016, MNRAS, 461, 1927
Penston M. V., Perez E., 1984, MNRAS, 211, 33P
Raimundo S. I., Vestergaard M., Koay J. Y., Lawther D., Casasola V., Peterson B. M., 2019, MNRAS, 486, 123
Ricci C., Trakhtenbrot B., 2022, arXiv e-prints, p. arXiv:2211.05132
Ricci C., Ueda Y., Koss M. J., Trakhtenbrot B., Bauer F. E., Gandhi P., 2015, ApJ, 815, L13
Ricci C., et al., 2016, ApJ, 820, 5
Ricci C., et al., 2017, ApJS, 233, 17

---

1 https://www.bass-survey.com
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 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.

This paper has been typeset from a TeX/LaTeX file prepared by the author.

| BAT ID | Counterpart Name | Observation dates | Instruments |
|--------|------------------|------------------|-------------|
| BAT135 | ESO 416–G002     | 2001-11-21       | AAO/6dF     |
|        |                  | 2017-06-24       | VLT/Xshooter|
|        |                  | 2021-12-12       | Magellan/MagE|
| BAT150 | 2MASX J02502722+4647295 | 2011-06-01 | Perkins/DeVeny |
|        |                  | 2018-09-09       | Palomar/DBSP |
|        |                  | 2019-08-29       | Palomar/DBSP |
| BAT155 | LEDA 90641       | 2011-09-29       | SPM/BC      |
|        |                  | 2017-08-31       | Palomar/DBSP |
| BAT235 | 1RXSJ044154.5–082639 | 1994-06-10 | MPG/EFOSC2 |
|        |                  | 2020-11-12       | Palomar/DBSP |
| BAT301 | ESO 424–12       | 2008-12-03       | SPM/BC      |
|        |                  | 2013-11-23       | VLT/Xshooter |
|        |                  | 2013-12-11       | VLT/Xshooter |
| BAT607 | NGC 4235         | 2005-01-16       | APO/SDSS    |
|        |                  | 2015-05-13       | VLT/Xshooter |
| BAT862 | SDSS J170859.13+215308.1 | 2004-06-21 | APO/SDSS |
|        |                  | 2020-10-23       | Palomar/DBSP |
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 normalised using the median flux density across each spectral window and dotted lines show the rest-frame wavelengths of Balmer $H_\beta \lambda 4861$ and $H_\alpha \lambda 6563$. 
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 normalised using the median flux density across each spectral window and dotted lines show the rest-frame wavelengths of Balmer H\(\beta\) \(\lambda4861\) and H\(\alpha\) \(\lambda6563\).