

PS1-13cbe: the rapid transition of a Seyfert 2 to a Seyfert 1

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ABSTRACT

We present a nuclear transient event, PS1-13cbe, that was first discovered in the Pan-STARRS1 survey in 2013. The outburst occurred in the nucleus of the galaxy SDSS J222153.87+003054.2 at $z = 0.123\,55$, which was classified as a Seyfert 2 in a pre-outburst archival Sloan Digital Sky Survey (SDSS) spectrum. PS1-13cbe showed the appearance of strong broad H α and H β emission lines and a non-stellar continuum in a Magellan spectrum taken 57 d after the peak of the outburst that resembled the characteristics of a Seyfert 1. These broad lines were not present in the SDSS spectrum taken a decade earlier and faded away within 2 yr, as observed in several late-time MDM spectra. We argue that the dramatic appearance and disappearance of the broad lines and a factor of ~ 8 increase in the optical continuum are most likely caused by variability in the pre-existing accretion disc than a tidal disruption event, supernova, or variable obscuration. The time-scale for the turn-on of the optical emission of ~ 70 d observed in this transient is among the shortest observed in a ‘changing-look’ active galactic nucleus.

Key words: accretion, accretion discs – black hole physics – galaxies: active – galaxies: nuclei.

1 INTRODUCTION

The axisymmetric unification model of active galactic nuclei (AGNs) suggests that there can be different types of AGNs based on the angle towards the line of sight. However, it is believed that the simple orientation-based model cannot fully explain the Type 1 (both narrow and broad emission lines are present in the spectra) and Type 2 (only narrow emission lines are present in the spectra) classification scheme because this model is challenged when different AGN types are observed in the same object at

different epochs of time. One alternative suggestion is that some Type 2s were Type 1s and their engine is now not active anymore or basically turned off; therefore, the Type 2s are evolved version of the Type 1s (Penston & Pérez 1984; Runnoe et al. 2016). This alternative view was first suggested based on the observations of broad emission lines disappearance in the Type 2 NGC 4151 (Lyutyj, Oknyanskij & Chuvpav 1984; Penston & Pérez 1984) and 3C 390.3 (Penston & Pérez 1984).

The term ‘changing look’ (CL) was first used for the AGNs that showed X-ray absorption variations (Matt, Guainazzi & Maiolino 2003; Puccetti et al. 2007; Bianchi et al. 2009; Risaliti et al. 2009; Marchese et al. 2012). Recently, this term has also been used to

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describe the type of AGNs that have been observed to optically transition from Type 1 to Type 1.8, 1.9, and 2 or vice versa, by the sudden appearance or disappearance of broad emission lines such as the broad $H\beta$ emission line (MacLeod et al. 2016; Runnoe et al. 2016). In some objects, the broad emission lines disappeared and the continuum faded completely (Collin-Souffrin, Alloin & Andrillat 1973; Tohline & Osterbrock 1976; Denney et al. 2014; Sanmartim, Storchi-Bergmann & Brotherton 2014; Barth et al. 2015; Runnoe et al. 2016), while in others broad emission lines appeared or, in other words, the AGN ‘turned on’ (Cohen et al. 1986; Storchi-Bergmann, Baldwin & Wilson 1993; Aretxaga et al. 1999; Eracleous & Halpern 2001; Shappee et al. 2014). These objects are mostly at low redshift with low absolute luminosities. However, recently LaMassa et al. (2015) discovered a luminous CL AGN with a redshift of $z = 0.31$ that transitioned from Type 1 quasar to a Type 1.9 AGN in ~ 9 yr. Subsequent studies (MacLeod et al. 2016; Runnoe et al. 2016; MacLeod et al. 2018) have started finding larger samples in the Sloan Digital Sky Survey (SDSS). Most recent, Gezari et al. (2017) discovered a quasar with a rapid ‘turn-on’ time-scale of < 1 yr that demonstrated one of the fastest changes of state to date.

The luminosities of Seyfert galaxies have been observed to vary over time. Variability has been detected in a wide range of wavelengths with time-scales from hours to years with the shortest in X-rays that show variation time-scales of a few hours in Seyfert galaxies (Green, McHardy & Lehto 1993; Nandra et al. 1997). The observed average variability time-scale in the optical in Seyfert galaxies is of the order of weeks to months (Kaspi et al. 1996; Givon et al. 1999). Accretion disc instabilities are the most promising model as the source of this variability (Kawaguchi et al. 1998; Kelly, Bechtold & Siemiginowska 2009).

Here, we report the rapid turn-on (~ 70 d) of a nuclear transient, PS1-13cbe, from a galaxy at redshift $z = 0.12355$ classified as a Seyfert 2 in a pre-event SDSS spectrum that was accompanied by the appearance of broad Balmer lines and hence a transition to a Seyfert 1. This represents the most rapid ‘turn-on’ in a CL AGN to date. We discuss the observations in Sections 2 and 3. We discuss the possible scenarios for the origin of the variations observed in PS1-13cbe in Section 4. We summarize and present our conclusions in Section 5. Throughout this work, we are assuming a standard Λ CDM cosmology with $H_0 = 69.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.286$, and $\Omega_\Lambda = 0.714$ parameters (Bennett et al. 2014) that yields a luminosity distance of $d_L = 582 \text{ Mpc}$. All magnitudes are in the AB system and all dates are UT. We assume a Galactic extinction value of $E(B - V) = 0.06$ (Schlafly & Finkbeiner 2011).

2 OBSERVATIONS OF PS1-13CBE

The Medium Deep Survey (MDS) of the Pan-STARRS1 (PS1) sky survey performed daily (in-season) deep monitoring of ten ~ 7 sq. deg. fields over the years 2010–2014 to find transient and variable sources. The typical observation sequence was composed of g_{P1} and r_{P1} bands on the first night, i_{P1} on the next night, and then z_{P1} on the third night. This pattern was repeated during the ~ 6 months of the observing season and was only interrupted by the weather and times near full moon, when observations in the y_{P1} filter were taken. A more complete description of the survey and photometric system was given by Tonry et al. (2012) and Chambers et al. (2016).

On 2013 July 9, we detected a transient event, PS1-13cbe, at coordinates $\alpha = 22^{\text{h}}21^{\text{m}}53.86^{\text{s}}$, $\delta = +00^{\circ}30'54.56''$ (J2000) coincident with the nucleus of a galaxy using the photpipe transient discovery pipeline, described by Rest et al. (2014) and

Scolnic et al. (2018). The host galaxy was observed as part of SDSS and given the name SDSS J222153.87+003054.2 (hereafter SDSS J2221+0030), with a spectroscopic redshift of $z = 0.12355$ (Ahn et al. 2014). We constructed a difference image light curve for PS1-13cbe using the PS1 transient pipeline (Scolnic et al. 2018). The template images were created from a stack of high-quality observations excluding the observing season containing the outburst (the year 2013) and were then subtracted from all observations of the transient. It is important to note that this photometry represents a flux difference relative to the host contribution present in the template (which is consistent with the SDSS photometry; Ahn et al. 2014). We include the PS1 photometry in Table 1.

2.1 Optical photometry

As shown in Fig. 1, the light curves of PS1-13cbe were constant and consistent with zero change in flux relative to the baseline in the template for three observational seasons and then showed a rise peaking at MJD 56512.6, decline, and a second rise ($g_{\text{P1}} = 19.5$ mag at peak; see Fig. 2). The g_{P1} -band luminosity showed a rise of about $\sim 1.5 \times 10^{43} \text{ erg s}^{-1}$ from the base luminosity in the course of ~ 70 d and then declined to $\sim 0.7 \times 10^{43} \text{ erg s}^{-1}$ in ~ 50 d and rose back up again to $\sim 1 \times 10^{43} \text{ erg s}^{-1}$ in the course of next ~ 50 d, at which point the MDS ended.

With the SDSS value for the quiescent host flux, $g' = 19.21 \pm 0.01$ mag (Ahn et al. 2014), and $g_{\text{P1}} = 19.5$ mag for PS1-13cbe at the peak of the outburst, we can see that the total luminosity of the galaxy increased by $\gtrsim 75$ per cent. However, the quiescent host flux value is dominated by star light. We estimate that the central AGN contributes $\lesssim 10$ per cent of the continuum flux in the quiescent spectrum taken by SDSS because the absorption lines from star light are not noticeably diluted by a non-stellar continuum, so the amplitude of the outburst from the AGN must be significantly larger, as discussed below.

After the MDS ended, we obtained late-time photometry in g' using the MDM4K and Templeton detectors on the 2.4 m Hiltner and 1.3 m McGraw-Hill telescopes at MDM Observatory on 2015 November 18 and 2017 June 18, respectively. The total magnitude of the host galaxy (including any possible transient contribution) was $g' = 19.23 \pm 0.05$ mag ($g' = 19.22 \pm 0.13$ mag) at 831 (1408) d after the peak, which are consistent with the SDSS pre-outburst photometry. Therefore, the system returned to the baseline flux value in $\lesssim 2$ yr after the outburst.

2.2 Observations of the host galaxy

In addition to the SDSS observation of the host (~ 10 yr before the outburst), the source was detected by the AllWISE survey in the $W1$, $W2$, $W3$, and $W4$ bands with catalogued values of 17.82 ± 0.037 , 18.20 ± 0.34 , 16.65 ± 0.23 , and 15.13 ± 0.37 mag, respectively (~ 3 yr before the outburst; Chang et al. 2015). We also obtained photometry using the Neil Gehrels *Swift* Observatory (Gehrels et al. 2004) with the UV Optical Telescope (UVOT; Roming et al. 2005) in the u , $uvw1$, and $uvw2$ filters on 2016 November 27–29 (~ 3 yr after the outburst) and we measure values of 21.10 ± 0.13 , 21.76 ± 0.21 , and 22.41 ± 0.19 mag, respectively.

2.3 X-ray photometry

We obtained an X-ray observation of SDSS J2221+0030 using the X-ray telescope (XRT; Burrows et al. 2003) on *Swift* with a total exposure time of 7.1 ks between 2016 November 27 and November

Table 1. Photometry of PS1-13cbe.

Data of observation (MJD)	Epoch (days)	Filter	Mag (observed)	Mag Uncertainty
56217.3	−295.3	g_{p1}	(23.5)	–
56475.5	−37.1	g_{p1}	19.89	0.03
56480.5	−32.1	g_{p1}	19.79	0.03
56486.6	−26.0	g_{p1}	19.76	0.03
56489.5	−23.1	g_{p1}	19.91	0.03
56501.4	−11.2	g_{p1}	19.79	0.03
56507.6	−5.0	g_{p1}	19.76	0.03
56512.5	−0.1	g_{p1}	19.66	0.03
56518.5	5.9	g_{p1}	19.85	0.03
56531.5	18.9	g_{p1}	20.16	0.04
56534.5	21.9	g_{p1}	20.20	0.04
56539.4	26.8	g_{p1}	20.30	0.04
56545.3	32.7	g_{p1}	20.38	0.04
56548.3	35.7	g_{p1}	20.42	0.06
56563.3	50.7	g_{p1}	20.49	0.05
56571.2	58.6	g_{p1}	20.50	0.04
56574.2	61.6	g_{p1}	20.43	0.06
56590.3	77.7	g_{p1}	20.35	0.04
56593.3	80.7	g_{p1}	20.24	0.04
56596.2	83.6	g_{p1}	20.22	0.04
56601.2	88.6	g_{p1}	20.34	0.07
56628.3	115.7	g_{p1}	20.11	0.17
56285.2	−227.4	r_{p1}	(23.5)	–
56475.6	−37.0	r_{p1}	19.85	0.04
56479.5	−33.1	r_{p1}	19.75	0.04
56486.6	−26.0	r_{p1}	19.66	0.03
56489.5	−23.1	r_{p1}	19.80	0.03
56501.4	−11.2	r_{p1}	19.70	0.03
56507.6	−5.0	r_{p1}	19.64	0.03
56508.5	−4.1	r_{p1}	19.63	0.03
56512.6	0.0	r_{p1}	19.60	0.03
56518.5	5.9	r_{p1}	19.72	0.03
56531.5	18.9	r_{p1}	20.04	0.04
56534.5	21.9	r_{p1}	20.08	0.04
56538.3	25.7	r_{p1}	20.03	0.05
56545.3	32.7	r_{p1}	20.11	0.04
56571.2	58.6	r_{p1}	20.44	0.06
56574.3	61.7	r_{p1}	19.81	0.37
56590.3	77.7	r_{p1}	20.29	0.05
56593.3	80.7	r_{p1}	20.11	0.05
56596.3	83.7	r_{p1}	20.05	0.04
56597.3	84.7	r_{p1}	20.08	0.04
56626.2	113.6	r_{p1}	20.11	0.07
56284.2	−228.4	i_{p1}	(23.5)	–
56473.5	−39.1	i_{p1}	19.65	0.04
56476.6	−36.0	i_{p1}	19.60	0.04
56481.6	−31.0	i_{p1}	19.51	0.05
56484.5	−28.1	i_{p1}	19.42	0.03
56491.5	−21.1	i_{p1}	19.54	0.03
56505.4	−7.2	i_{p1}	19.46	0.03
56508.6	−4.0	i_{p1}	19.44	0.03
56513.6	1.0	i_{p1}	19.44	0.03
56516.5	3.9	i_{p1}	19.46	0.03
56520.5	7.9	i_{p1}	19.54	0.03
56532.4	19.8	i_{p1}	19.79	0.04
56538.4	25.8	i_{p1}	19.72	0.04
56540.4	27.8	i_{p1}	19.70	0.04
56550.5	37.9	i_{p1}	20.18	0.06
56558.4	45.8	i_{p1}	20.07	0.05
56564.4	51.8	i_{p1}	19.96	0.05
56567.2	54.6	i_{p1}	20.10	0.06
56569.3	56.7	i_{p1}	20.02	0.05
56575.3	62.7	i_{p1}	20.01	0.05

Table 1 – continued

Data of observation (MJD)	Epoch (days)	Filter	Mag (observed)	Mag Uncertainty
56588.4	75.8	i_{p1}	19.79	0.04
56597.2	84.6	i_{p1}	19.88	0.04
56599.3	86.7	i_{p1}	19.89	0.04
56626.2	113.6	i_{p1}	19.85	0.06
56216.2	−296.4	z_{p1}	(23.5)	–
56453.5	−59.1	z_{p1}	19.86	0.05
56456.6	−56.0	z_{p1}	19.71	0.04
56474.6	−38.0	z_{p1}	19.58	0.05
56477.5	−35.1	z_{p1}	19.67	0.04
56480.5	−32.1	z_{p1}	19.44	0.04
56482.5	−30.1	z_{p1}	19.41	0.03
56485.6	−27.0	z_{p1}	19.54	0.04
56488.4	−24.2	z_{p1}	19.55	0.03
56490.5	−22.1	z_{p1}	19.48	0.05
56492.5	−20.1	z_{p1}	19.54	0.04
56506.6	−6.0	z_{p1}	19.53	0.04
56511.6	−1.0	z_{p1}	19.47	0.04
56517.4	4.8	z_{p1}	19.49	0.04
56519.6	7.0	z_{p1}	19.60	0.04
56521.6	9.0	z_{p1}	19.65	0.04
56530.4	17.8	z_{p1}	19.81	0.04
56536.5	23.9	z_{p1}	19.84	0.05
56539.4	26.8	z_{p1}	19.91	0.05
56541.3	28.7	z_{p1}	19.79	0.05
56544.3	31.7	z_{p1}	19.87	0.06
56549.3	36.7	z_{p1}	19.90	0.06
56557.5	44.9	z_{p1}	20.07	0.06
56568.3	55.7	z_{p1}	20.35	0.14
56570.3	57.7	z_{p1}	20.03	0.06
56584.3	71.7	z_{p1}	19.92	0.05
56589.3	76.7	z_{p1}	19.94	0.05
56592.3	79.7	z_{p1}	19.87	0.05
56595.2	82.6	z_{p1}	19.84	0.05
56600.3	87.7	z_{p1}	19.81	0.05
56613.3	100.7	z_{p1}	19.87	0.05
56628.2	115.6	z_{p1}	20.03	0.06
56266.3	−246.0	y_{p1}	(23.5)	–
56434.6	−78.0	y_{p1}	20.63	0.17
56436.6	−76.0	y_{p1}	20.42	0.10
56437.6	−75.0	y_{p1}	20.73	0.29
56454.6	−58.0	y_{p1}	19.70	0.11
56467.5	−45.0	y_{p1}	19.82	0.04
56484.5	−28.0	y_{p1}	19.34	0.05
56493.6	−19.0	y_{p1}	19.50	0.03
56494.6	−18.0	y_{p1}	19.58	0.03
56511.5	−1.0	y_{p1}	19.37	0.03
56517.4	5.0	y_{p1}	19.32	0.06
56522.6	10.0	y_{p1}	19.66	0.04
56532.4	20.0	y_{p1}	19.66	0.04
56556.4	44.0	y_{p1}	19.73	0.03
56559.3	47.0	y_{p1}	19.94	0.09
56562.3	50.0	y_{p1}	19.88	0.11
56563.2	51.0	y_{p1}	19.89	0.04
56566.5	54.0	y_{p1}	20.04	0.17
56567.3	55.0	y_{p1}	19.77	0.14
56569.2	57.0	y_{p1}	20.03	0.19
56573.3	61.0	y_{p1}	20.00	0.08
56574.2	62.0	y_{p1}	19.89	0.19
56584.4	72.0	y_{p1}	19.72	0.04
56585.3	73.0	y_{p1}	19.96	0.07
56586.3	74.0	y_{p1}	20.15	0.05
56613.3	101.0	y_{p1}	19.79	0.04
56616.2	104.0	y_{p1}	19.88	0.08

Table 1 – *continued*

Data of observation (MJD)	Epoch (days)	Filter	Mag (observed)	Mag Uncertainty
56620.2	108.0	y_{p1}	19.80	0.04
56626.2	114.0	y_{p1}	19.70	0.17
56638.2	126.0	y_{p1}	19.77	0.04

Note: Magnitudes provided here are not reddening corrected and the epochs are relative to the peak in the rest frame. 3σ upper limit values are represented in parentheses.

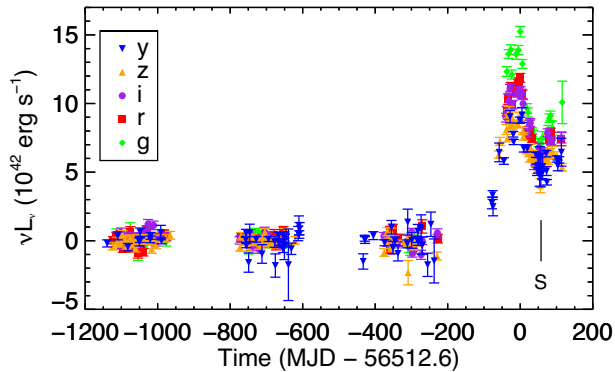


Figure 1. The observed transient luminosities of PS1-13cbe from the PS1 survey in the $grizyp_1$ filters after correction for Galactic extinction. S: marks the epoch of the LDSS spectrum (MJD 56570).

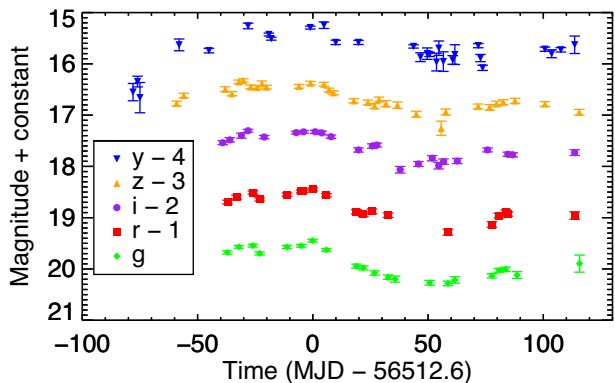


Figure 2. Light curves of PS1-13cbe in the $grizyp_1$ bands, corrected for Galactic extinction. Note the small-scale fluctuations in the light curve (such as near -20 d).

29. The host was not detected with a 3σ upper limit of 2.13×10^{-3} cts s^{-1} (0.3–10 keV). Using the Galactic neutral hydrogen column density in the direction of PS1-13cbe of $N_H = 4.49 \times 10^{20}$ cm^{-2} (Kalberla et al. 2005) and assuming no intrinsic absorption, and a typical photon index of $\Gamma = 2$, we calculate the unabsorbed X-ray flux to be $f_x(2-10 \text{ keV}) \leq 4.0 \times 10^{-14}$ $erg \text{ cm}^{-2} \text{ s}^{-1}$, which translates to $L_X \leq 1.6 \times 10^{42}$ $erg \text{ s}^{-1}$.

The absorbing column densities of Seyfert 2 galaxies range from 10^{22} to 10^{25} cm^{-2} (e.g. Risaliti, Maiolino & Salvati 1999) and therefore, assuming a minimum intrinsic column density of 10^{22} cm^{-2} for the host galaxy in addition to the Galactic value, we recalculate the unabsorbed X-ray flux to be $f_x(2-10 \text{ keV}) \leq 1.0 \times 10^{-13}$ $erg \text{ cm}^{-2} \text{ s}^{-1}$ or $L_X \leq 4.1 \times 10^{42}$ $erg \text{ s}^{-1}$. Additionally, using L_X and the empirical bolometric correction from Marconi et al. (2004), this corresponds to a minimal upper limit on the

bolometric luminosity of the object $L_{bol} \leq 0.6 \times 10^{44}$ $erg \text{ s}^{-1}$ 3 yr after the outburst, although this value can increase if the intrinsic absorption is higher (e.g. $L_{bol} \leq 9.0 \times 10^{45}$ $erg \text{ s}^{-1}$ for an intrinsic column density of 10^{24} cm^{-2}). We did not find any archival X-ray observations of the object before or at the time of the outburst.

2.4 Optical spectroscopy

A pre-outburst spectrum of SDSS J2221+0030 was obtained on 2003 May 26 by SDSS (Ahn et al. 2014). After the detection by PS1, we observed PS1-13cbe on 2013 October 5 (+57 d after peak) for 1200 s using the Low Dispersion Survey Spectrograph-3 (LDSS3) on the 6.5 m Magellan Clay telescope. We used a 1 arcsec-wide long slit with the VPH-all grism to cover the observed wavelength range 3700–10 000 \AA with a resolution of ~ 9 \AA .

At late times, we obtained five epochs of spectroscopy using the Ohio State Multiple Object Spectrograph on the 2.4 m Hiltner telescope at MDM Observatory (OSMOS; Martini et al. 2011). The first two spectra were taken on 2015 October 3 and 2015 November 12 using the 1.2 arcsec centre slit with a VPH-red grism and an OG530 filter that covered 5350–10 200 \AA (resolution = 5 \AA) in the observed frame. No significant spectral differences were present, so we combined these two observations for all subsequent analyses. The next two spectra were obtained on 2015 December 1 and 2016 November 16 using the same 1.2 arcsec centre slit and a VPH-blue grism that covered 3675–5945 \AA (resolution = 2 \AA) in the observed frame. The final spectrum was taken on 2017 June 18 using a 1.0 arcsec outer slit and VPH-red grism that covered 3930–9050 \AA (resolution = 4 \AA) in the observed frame.

We preprocess our data using standard procedures such as flat-fielding, bias subtraction, and wavelength calibration using arc lamps in IRAF.¹ Additionally, we removed cosmic rays using the L.A.Cosmic (Van Dokkum 2001) task. Finally, we calibrate our data using our own IDL procedures and observations of the standard stars BD+174708 for red spectra and Feige110 for blue spectra. All of the spectra for PS1-13cbe are shown in Fig. 3.

3 OBSERVATIONAL FEATURES OF PS1-13CBE

3.1 Host galaxy of PS1-13cbe

To isolate the emission lines of SDSS J2221+0030 and correct for stellar absorption lines, we simulated a galaxy model with the FAST 1.0 code (Kriek et al. 2009) using the archival SDSS spectrum and optical photometry in the $ugriz$ bands along with the *Swift* u , $uvw1$, and $uvw2$ photometry. We experimented with the initial parameters and generated the best fit with the stellar age of 3×10^9 yr and e-folding time-scale of $\tau \approx 10^9$ yr, by assuming the star formation history to be exponentially declining, the stellar initial mass function from Chabrier (2003), the Bruzual & Charlot (2003) spectral library, a Milky Way dust law (Cardelli, Clayton & Mathis 1989), and solar-like metallicity of $Z = 0.02$. The FAST model of the host galaxy is overplotted on the original SDSS spectrum (grey) in the bottom of the Fig. 3 (black).

¹IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

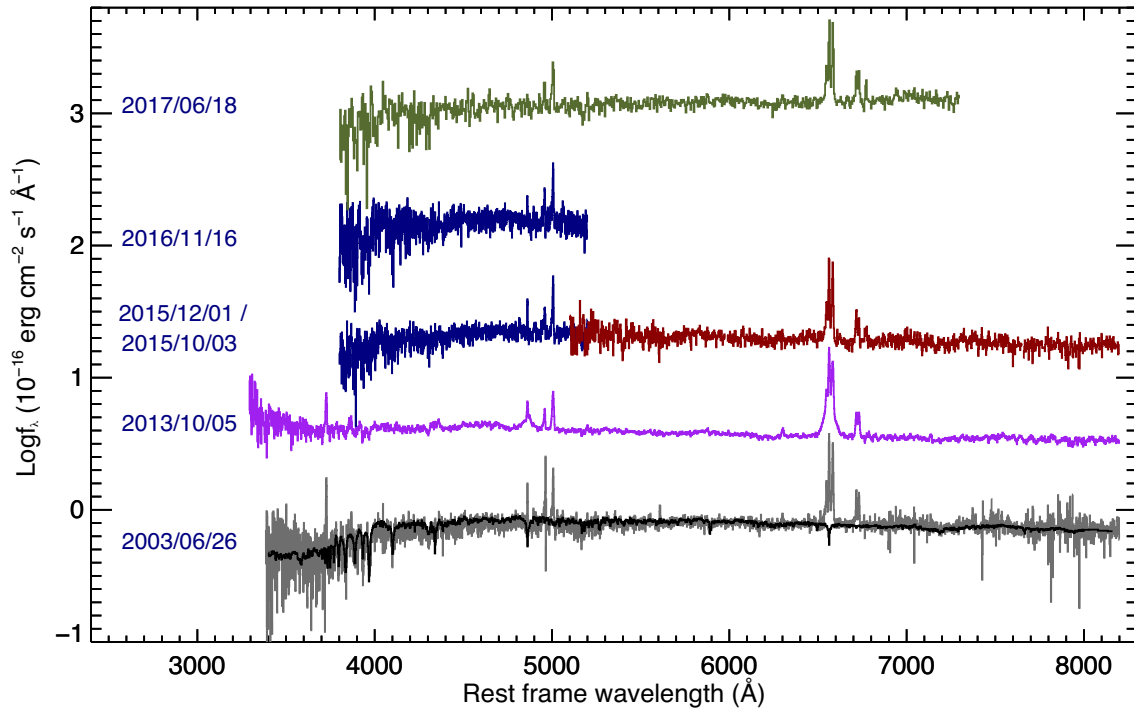


Figure 3. Optical spectra for PS1-13cbe, from bottom to top: host galaxy of PS1-13cbe from SDSS (grey), model of the host galaxy generated by FAST 1.0 (black), spectrum during outburst observed using LDSS3 (purple), spectra obtained with OSMOS in red and blue for the red and blue set-ups, respectively, and the most recent OSMOS spectrum (olive green).

After subtracting this model from the pre-outburst optical spectrum of the host galaxy of PS1-13cbe (bottom of Fig. 3 in grey), we fit the profiles of the narrow emission lines [S II] $\lambda\lambda 6717, 6731$, [O III] $\lambda\lambda 4959, 5007$, [O II] $\lambda 3727$, [O I] $\lambda 6300$, [N II] $\lambda\lambda 6549, 6583$, H α , and H β . It has been shown that a model for narrow emission lines can be obtained from [S II] lines in most cases (Ho et al.). By using this fact, we constrained parameters of the Gaussian profiles of the other narrow lines. The lines were not well modelled with single Gaussians, so we used double Gaussian profiles to fit the line profile of all the narrow lines except [O II] $\lambda 3726$ and [O I] $\lambda 6300$. In Fig. 4, we plot the line ratios in excitation diagrams (Baldwin, Phillips & Terlevich 1981). We also show the extreme star formation line (Kewley et al. 2001, 2006), the pure star formation line (Kauffmann et al. 2003), and the Seyfert-LINER classification line (Kewley et al. 2006; Fernandes et al. 2010). Additionally, we show 30 000 randomly selected galaxies (shaded area in Fig. 4) with emission-line fluxes from the MPA-JHU DR7 catalogue² (Aihara et al. 2011). The automatic Portsmouth pipeline from SDSS classified the host galaxy of PS1-13cbe as a LINER (Sarzi et al. 2006); however, our emission-line ratios calculated from the SDSS spectrum after subtraction of the stellar continuum (navy squares) classify the host galaxy as a clear Seyfert (Fig. 4).

Next, we constructed the spectral energy distribution (SED) of the host galaxy using the observed and archival photometry data. We also scaled and plotted SEDs of an Sb spiral galaxy and a Seyfert 2 galaxy from the SWIRE template library (Polletta et al. 2007) alongside the SED of the host (see Fig. 5). The SED of the Seyfert 2 galaxy fits well from the mid-IR to UV, including the contribution from star light. As we can see in Fig. 5, the SED of the spiral galaxy fits the optical and UV part of the host SED as well;

however, there is a broad excess in the mid-IR (*W3* and *W4*). This excess is because of the contribution of dust heated by the AGN in the host galaxy. After subtracting the host contribution (using the Sb template) from the observed values, we estimate the luminosity of the AGN component to be $\nu L_\nu(W4) \approx (1.63 \pm 0.65) \times 10^{43}$ erg s⁻¹. Then, using a bolometric correction factor of 10.1 ± 1.4 for the *W4* band from Runnoe, Brotherton & Shang (2012), we estimate the total bolometric luminosity of the AGN to be $L_{\text{bol}}(W4) \approx (1.65 \pm 0.65) \times 10^{44}$ erg s⁻¹.

Furthermore, narrow emission lines are possible indicators of the intrinsic bolometric luminosity (Netzer 2009). We estimate the bolometric luminosity of the AGN from the luminosity of the narrow [O III] $\lambda 5007$ emission line in the SDSS spectrum and used the conversion that $L_{\text{bol}} = 3500L(\lambda 5007)$, which has a variance of 0.38 dex by assuming a standard AGN SED (Heckman et al. 2004). This results in an estimate of $L_{\text{bol}} = 1.6 \times 10^{44}$ erg s⁻¹, which is consistent with the bolometric luminosity calculated using the *W4* band above. This luminosity can be an overestimate if some of the [O III] emission originates from star formation. However, as shown in Fig. 4, SDSS J2221+0030 is classified as a clear Seyfert galaxy and therefore narrow line excitation is dominated by the AGN. Moreover, as we discussed in Section 2.3, we estimate the upper limit on the bolometric luminosity in quiescence from the X-ray non-detection to be $\leq 0.6 \times 10^{44}$ erg s⁻¹, which is consistent with the bolometric luminosity estimated before the outburst in quiescence. This is only an estimate because the X-ray flux is a non-detection, whereas having an X-ray detection would help us to have a better estimate of the intrinsic absorption and column density.

3.2 Astrometry

To find the location of PS1-13cbe in its host galaxy, we performed relative astrometry between the PS1/MDS template images of the

²<http://wwwmpa.mpa-garching.mpg.de/SDSS/DR7/>

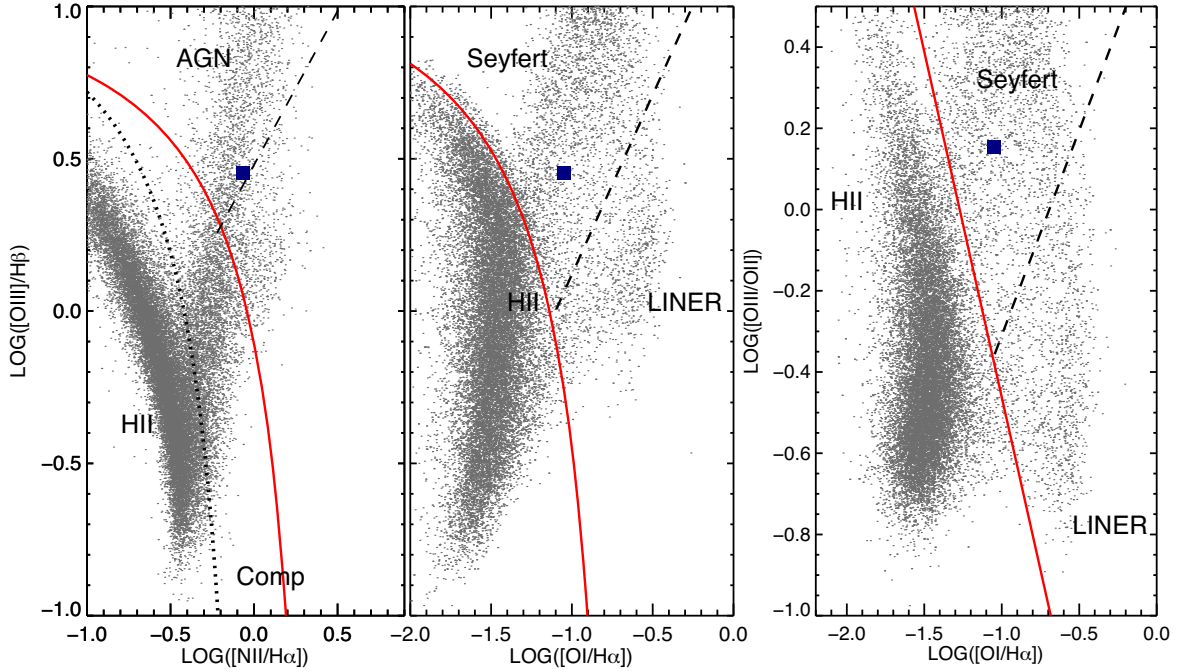


Figure 4. The excitation diagrams using the $[\text{N II}] \lambda 6583/\text{H}\alpha$, $[\text{O I}] \lambda 6300/\text{H}\alpha$, $[\text{O III}] \lambda 5007/\text{H}\beta$, and $[\text{O III}] \lambda 5007/[\text{O II}] \lambda 3726$ line ratios (Baldwin et al. 1981; Kewley et al. 2006). The navy blue squares display the position of the host galaxy of PS1-13cbe. The shaded area represents the location of the SDSS galaxies calculated using MPA-JHU where darker regions represent higher number density of the galaxies. The extreme star formation line (solid red; Kewley et al. 2001, 2006), the revised star formation line (dotted black; Kauffmann et al. 2003), and the Seyfert-LINER classification line (dashed black; Kewley et al. 2006; Fernandes et al. 2010) are also plotted. Comp: AGN/star-forming composites.

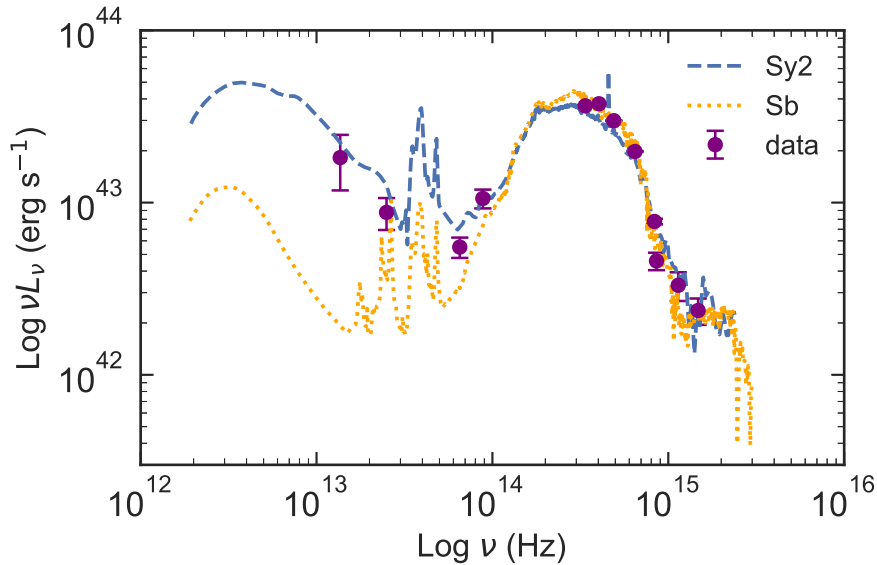


Figure 5. SED of SDSS J2221+0030 in quiescence (purple circles), scaled SED templates of an Sb spiral galaxy (dotted orange line), and a Seyfert 2 galaxy (dashed blue lines) from the SWIRE template library (Polletta et al. 2007). The host exhibits a mid-infrared (MIR) excess relative to the star-forming template due to an AGN.

host galaxy and the position of the transient reported by `photpipe`. First, we fit a two-dimensional Gaussian function to the templates in all filters to find the centroid of SDSS J2221+0030 and then, using the weighted average centroid coordinates of the transient, we calculate the offset of PS1-13cbe from the centre of its host galaxy to be $0.036 \text{ arcsec} \pm 0.035 \text{ arcsec}$ ($101 \pm 100 \text{ pc}$), consistent with the nucleus. We used a systematic astrometric error floor of 0.1 pixel to calculate the uncertainty in the offset (Scolnic et al.

2018). We show the position of PS1-13cbe relative to the centre of its host in the g_{P1} band in Fig. 6.

3.3 Multiband light curves of PS1-13cbe

We calculate the total optical luminosity light curve of PS1-13cbe using multiband observations shown in Fig. 1. This has been done by first finding the epochs where the g_{P1} and r_{P1} bands were observed

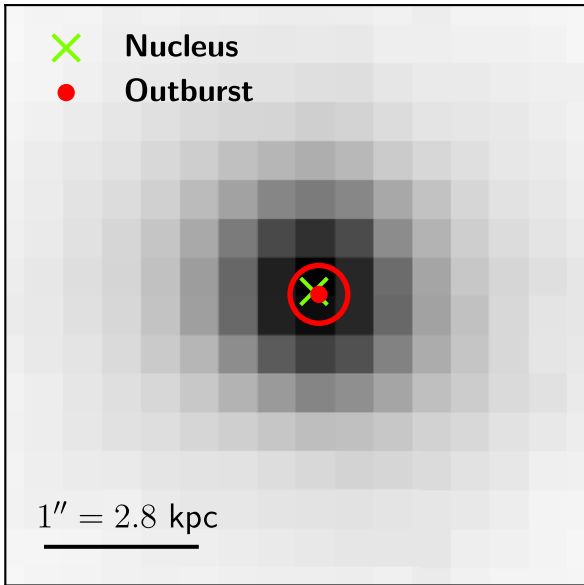


Figure 6. The g_{P1} PS1 template image of SDSS J2221+0030 showing the position of the centroid of the galaxy (green ‘X’) and the position of PS1-13cbe (red dot), and its position uncertainty is shown by a circle with a 5σ radius (red circle). The position uncertainty is dominated by the outburst.

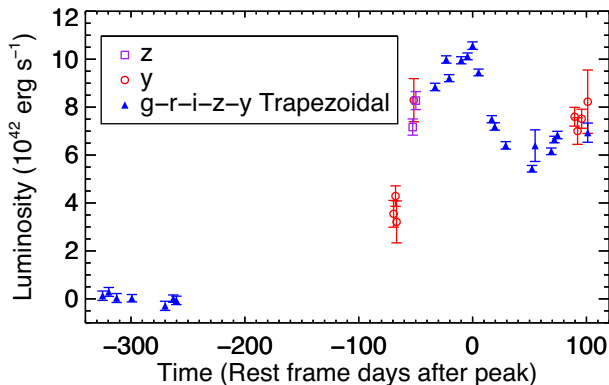


Figure 7. Total optical luminosity light curve of PS1-13cbe integrated over the $grizy_{P1}$ filters and relative to the baseline flux in the template images. The total optical luminosity was estimated using the spectral distribution at each epoch and the trapezoidal rule (blue triangles). The estimated luminosity at early and late times using the y_{P1} (red circles) and z_{P1} (purple squares) bands assumed the same colour correction as measured from those epochs with all filters.

simultaneously and then interpolating the i_{P1} , z_{P1} , and y_{P1} bands at these epochs using Legendre polynomials. Next, by integrating the spectral distribution at each epoch and using the trapezoidal rule, we calculate the total flux and thereafter optical luminosity over 3685–8910 Å in the rest frame. At late and early times, we had data only from the y_{P1} and z_{P1} bands, so we calculate the luminosity assuming the same colour correction as measured from those epochs with all filters. As seen in Fig. 7, the total optical luminosity of PS1-13cbe rises to a peak value of $(1.06 \pm 0.01) \times 10^{43}$ erg s^{−1} in the course of ~ 70 d, declines in next ~ 50 d, and then rises back up again.

Furthermore, to study the evolution in continuum colour and temperature while remaining agnostic about the overall SED of the transient, we fit both power law and blackbody models. We also calculate the $g - r$ colour and show it alongside the spectral index

and blackbody temperatures for all epochs in Fig. 8. The reason we chose the g_{P1} and r_{P1} bands as a proxy for the colour is that they were taken on the same night in the PS1 survey and do not need to be interpolated. No strong colour evolution during the outburst is evident in Fig. 8.

3.4 Spectral features of PS1-13cbe

In Fig. 3, we show the optical spectra for PS1-13cbe. The spectra of PS1-13cbe show remarkable evolution over the course of 14 yr. The spectra contain narrow and broad emission-line profiles, including hydrogen Balmer lines, [S II] $\lambda\lambda 6717, 6731$, [O III] $\lambda\lambda 4959, 5007$, [O II] $\lambda 3726$, [O I] $\lambda 6300$, and [N II] $\lambda\lambda 6549, 6583$. We note that the spectra were taken with different effective apertures (slit and seeing) and different spectral resolutions. We fit the $H\alpha + [N II]$ and $H\beta + [O III]$ complexes in order to investigate the presence of broad $H\alpha$ and $H\beta$ lines.

First, we scaled our OSMOS (blue set-up) and LDSS3 spectra using the flux of [O III] $\lambda 5007$ from the SDSS spectrum and scaled the OSMOS red set-up using the [N II] flux from SDSS. We did these scalings with the assumptions that these narrow lines are centrally concentrated in the host and that the fluxes do not change in such a short time-scale because it has been shown that narrow emission lines only slowly vary over decades (Peterson et al. 2013). In addition, the LDSS3 spectrum was taken during the outburst and contains transient flux. In that case, first we fit a power law $f_\nu \propto \nu^\alpha$ to the optical photometry from PS1 at the epoch when the spectrum was taken, where $\alpha = -0.58$. After that, we constructed a model from a linear combination of the power-law continuum and the host galaxy model shown in Fig. 3. Additionally, we smoothed this model by a Gaussian with full width at half-maximum (FWHM) = 5 Å to better match the resolution of our data and subtracted it from the LDSS3 spectrum, isolating the emission-line spectrum.

Next, we fit the [S II] lines using double Gaussian profiles and use this model to constrain the multicomponent Gaussian profiles that were used to fit the $H\alpha + [N II]$ complex to reduce the number of free parameters (Ho et al.). Specifically, we model emission lines using two Gaussian profiles for each narrow line and one broad component for $H\alpha$ and simultaneously fit for parameters of the broad and narrow lines. We fix the narrow components to the wavelengths of $H\alpha$ and [N II] $\lambda\lambda 6549, 6583$. Also, we fix the widths and relative amplitudes of the two Gaussian components of the narrow lines using the values from the [S II] model, leaving only the overall amplitudes of the narrow $H\alpha$ and [N II] lines as free parameters. The parameters of the broad component of $H\alpha$ were allowed to vary freely. We fit the [O III] $\lambda\lambda 4959, 5007$ lines using two Gaussian profiles for each narrow line without constraining the parameters. For $H\beta$, however, we use two Gaussian profiles, a single one for the narrow component with just the centroid fixed and allowing the other parameters to vary, and one for the broad component with no constraints.

The SDSS and OSMOS spectra lack transient flux, so we only subtract a scaled galaxy model and perform the same procedure as for the LDSS3 spectrum to fit the narrow and broad emission lines, with the exception of fixing the width and the centroid of the broad component of both $H\alpha$ and $H\beta$ to the values derived from LDSS3 spectra, allowing only the normalization to vary. We show the resultant Gaussian fits to the $H\alpha + [N II]$ and $H\beta + [O III]$ emission lines in Figs 9 and 10, respectively.

As we show in Figs 9 and 10, the existence of the broad $H\alpha$ and $H\beta$ components is clear in the LDSS3 spectrum (a weak broad $H\gamma$ emission line was also detected). Ho et al. () found that they

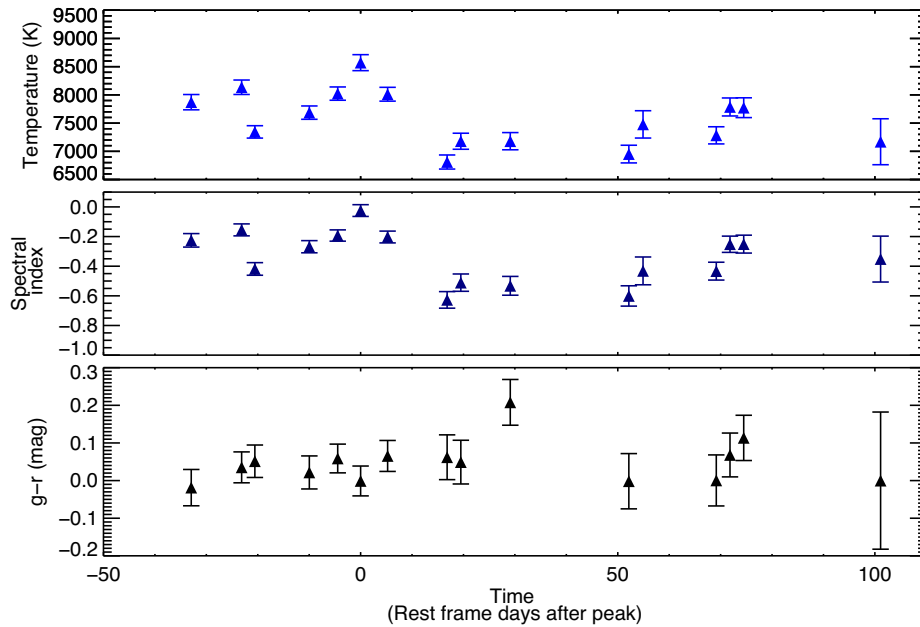


Figure 8. *Top:* Rest-frame blackbody temperature from fitting the optical photometry. *Middle:* Rest-frame spectral index from fitting a power law $f_\nu \propto \nu^\alpha$ to the optical photometry, where α is the spectral index. *Bottom:* Observed $g - r$ colour diagram. All the three panels show little or no evolution during the outburst.

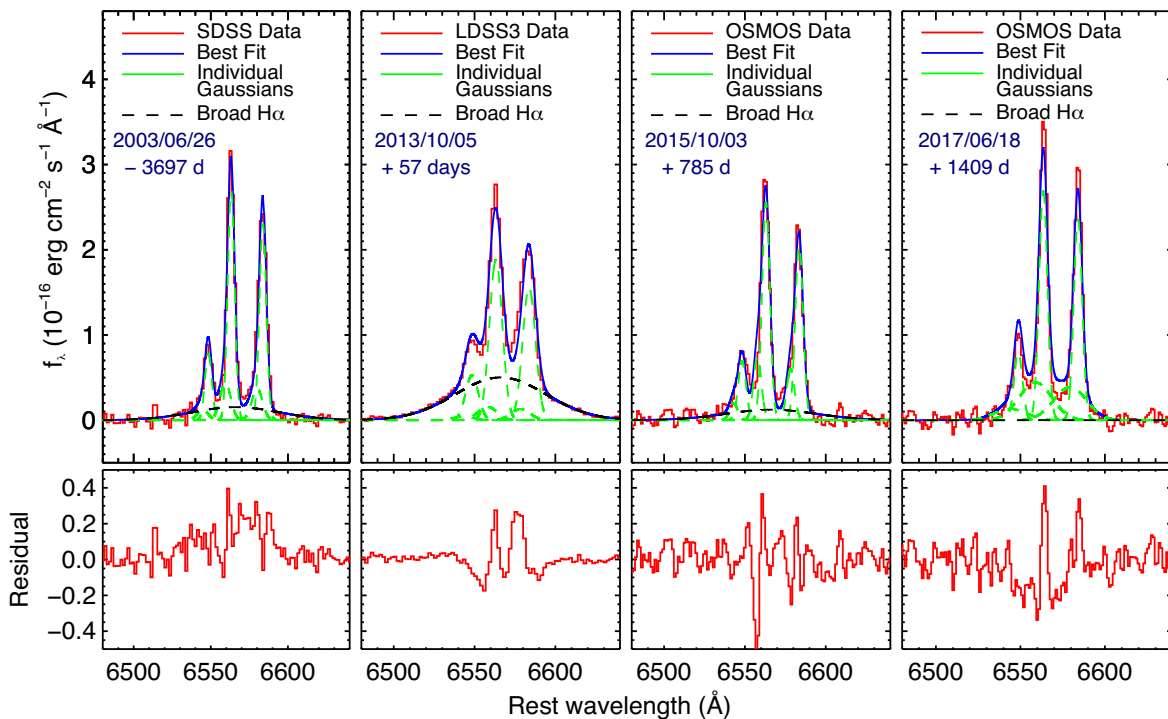


Figure 9. Continuum-subtracted $H\alpha$ line profiles. *Top:* Multiple-component Gaussian fit to the $H\alpha + [N II]$ emission lines (blue), individual components (dashed green) and broad component of the $H\alpha$ (dashed black). *Bottom:* The fit residuals. *Top-left (on each panel):* Observation date and numbers of days before/after the peak (navy blue).

could reliably extract a weak broad $H\alpha$ component that comprised ≥ 20 per cent of the $H\alpha + [N II]$ blend from spectra with spectral resolution close to ours. As shown in Fig. 9, there is marginal evidence for a broad component of $H\alpha$ in the SDSS and OSMOS data, which is 21 and 17 per cent of the flux in the $H\alpha + [N II]$ complex, respectively. However, it is notable that there are visible

wiggles in the residuals of the fit from the spectra that suggest the broad emission-line profiles are not purely Gaussian. For this reason, we are not confident that broad $H\beta$ line in the SDSS data and broad lines in the OSMOS are real and are not result of deviations from a Gaussian profile. We report the measured luminosities of the broad components of the $H\alpha$ and $H\beta$ emission lines in Table 2.

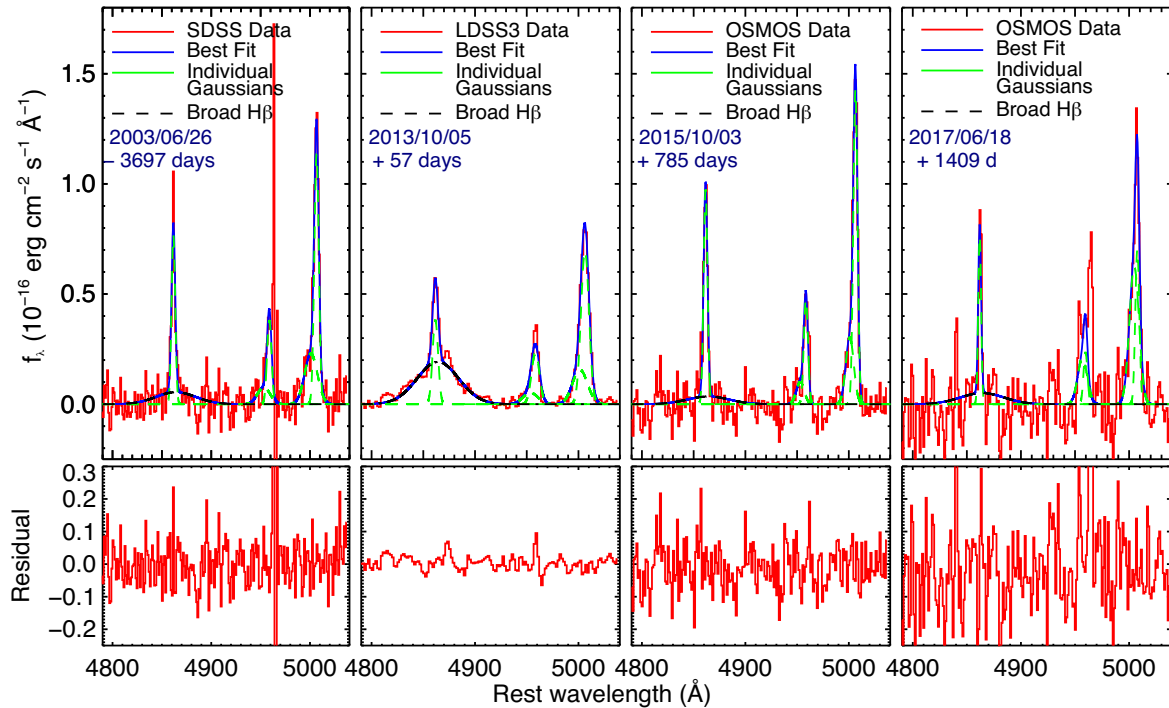


Figure 10. Continuum-subtracted $H\beta$ line profiles. *Top:* Multiple-component Gaussian fit to the $H\beta$ + [O III] emission lines (blue), individual components (dashed green) and broad component of the $H\beta$ (dashed black). *Bottom:* The fit residuals. *Top-left (on each panel):* Observation date and numbers of days before/after the peak (navy blue). Strong residuals are present in the red wing of $\lambda 4959$ due to poor subtraction of the 5577 \AA sky line.

Table 2. Luminosity of broad lines.

Date (UT)	Instrument	Broad $H\alpha$	Broad $H\beta$
2003 June 26	SDSS	4.87 ± 0.37	1.25 ± 0.39
2013 Oct 5	LDSS3	16 ± 0.28	4.39 ± 0.22
2015 Oct 3	OSMOS	3.92 ± 0.45	< 1.2
2016 Nov 16	OSMOS	–	< 0.85
2017 June 18	OSMOS	< 0.86	< 1.14

Note: Luminosity of broad $H\alpha$ and $H\beta$ lines in SDSS, LDSS3, and OSMOS spectra reported in units of $10^{40} \text{ erg s}^{-1}$. Non-detections are reported as 3σ upper limits.

As mentioned in Section 3.1, we classified the SDSS spectrum to be that of a Seyfert. Moreover, the galaxy can be classified as a Seyfert 1.9/2 galaxy since it just shows narrow emission lines and possible weak broad $H\alpha$ without any sign of a broad $H\beta$ line, as shown in the left-hand panels of Figs 9 and 10. At the time of the outburst, the spectrum of PS1-13cbe taken with LDSS3 showed broad $H\alpha$ and $H\beta$ components with FWHM velocities of 3385 ± 32 and $3277 \pm 110 \text{ km s}^{-1}$, respectively. These high values of FWHM are the sign of the high velocity, dense, and highly ionized gas clouds in the broad-line region (BLR) close to the central black hole (BH) where the broad emission lines originate from. The presence of these broad lines suggests that the galaxy transformed from a Seyfert 1.9/2 to a Seyfert 1 galaxy. On the other hand, we did not detect broad emission lines in the spectra taken with OSMOS and that means the host galaxy of PS1-13cbe transformed back from a Seyfert 1 to a Seyfert 2 galaxy in less than 2 yr and continues in that state as there are no signs of broad lines in spectra taken with OSMOS ~ 4 yr after the peak of the outburst.

We estimate the mass of the central BH using two methods. The first method uses the stellar kinematics and the revised scaling

relation between the supermassive black hole (SMBH) mass and stellar velocity dispersion (McConnell & Ma 2013), where $\sigma = 93.52 \text{ km s}^{-1}$ was provided from the SDSS spectrum of the host galaxy, and results in an estimate of $M_{\text{BH}} = 2.9^{+3.5}_{-1.7} \times 10^6 M_{\odot}$. However, this estimation is subject to uncertainties because of the large scatter and lack of constraints at the low σ and M_{BH} region of the $M_{\text{BH}}-\sigma$ scaling relation, particularly in a case where we do not have a decomposition of the galaxy that separates the bulge component (Kormendy & Ho 2013; McConnell & Ma 2013)

The mass of the SMBH can also be estimated using photoionization equilibrium, by applying a mass–scaling relationship based on the FWHM of the broad $H\beta$ emission line and continuum luminosity. Therefore, using the measured FWHM $\approx 3277 \text{ km s}^{-1}$, intrinsic luminosity at 5100 \AA (λL_{5100}) of $(6.2 \pm 0.2) \times 10^{42} \text{ erg s}^{-1}$ at the time of the spectrum, and the mass–scaling relationship of Vestergaard & Peterson (2006), we calculate the mass of the central BH to be $(2.2 \pm 0.1) \times 10^7 M_{\odot}$. We note that the values used in this calculation are measured during the outburst and can be affected by the changes in the accretion structure and also rely on the assumption that the (unknown) shape of the ionizing continuum is similar to those objects used to calibrate the scaling relationship. We prefer this mass estimate in our calculations below because we believe the assumptions behind this photoionization calculation to be more robust.

The Eddington luminosity for this BH mass is $L_{\text{Edd}} = (2.7 \pm 0.1) \times 10^{45} \text{ erg s}^{-1}$. We also calculate the intrinsic luminosity at 5100 \AA (λL_{5100}) for PS1-13cbe that is $(1.16 \pm 0.01) \times 10^{43} \text{ erg s}^{-1}$ at the time of the peak and then we estimate the bolometric luminosity using λL_{λ} and a conversion factor of 8.1 (Runnoe et al. 2012) to convert from monochromatic to bolometric luminosity to be $(9.4 \pm 0.1) \times 10^{43} \text{ erg s}^{-1}$. This results in an Eddington parameter of $\lambda_{\text{Edd}} = L_{\text{bol}}/L_{\text{Edd}} \approx 0.03$ at the peak of the outburst.

4 INTERPRETATION OF THE FEATURES OF PS1-13CBE

In Fig. 11, we show the spectrum of PS1-13cbe at the time of the outburst (after subtraction of the star light component from the host galaxy model) alongside the comparison objects, including a QSO (SDSS QSO template), a Type IIIn SN (SN1994Y; Filippenko 1997), and a tidal disruption event (TDE: ASASSN-14li; Holoien et al. 2015). All of these objects show the presence of broad H α and H β lines with emission-line profiles similar to the PS1-13cbe spectrum. It is notable that the PS1-13cbe spectrum closely resembles that of the QSO template, which is consistent with AGN activity. However, we estimate the spectral index at the epoch of the LDSS3 spectrum to be $\alpha = -0.58$, which is redder than the highly variable QSOS studied in Wilhite et al. (2005) that had a spectral index of $\alpha = -2$ for the average difference spectrum (bright phase minus faint phase).

In this section, we discuss SNe, TDE, and AGN variability as three possible interpretations for PS1-13cbe. However, before discussing the details about these scenarios we have summarized the key features of PS1-13cbe:

- (i) PS1-13cbe occurred in the nucleus of a Seyfert 2 galaxy with a central SMBH with a mass of $\sim 2 \times 10^7 M_{\odot}$.
- (ii) PS1-13cbe brightened in the course of ~ 70 d and reached a peak total optical luminosity of $(1.06 \pm 0.01) \times 10^{43}$ erg s $^{-1}$.
- (iii) The temperature of PS1-13cbe roughly stayed constant and $g - r$ (transient component) did not show any colour evolution.
- (iv) The spectra of PS1-13cbe show significant evolution over the course of ~ 12 yr where broad H α , H β , and H γ lines appear and disappear from the spectra.

4.1 Type IIIn supernovae interpretation of PS1-13cbe

Type IIIn SNe show broad H Balmer lines and blue continua in their optical spectra that can resemble the spectra of AGNs in specific phases of their evolution (Filippenko 1989). As we show in Fig. 11, the lack of P Cygni profiles in the spectrum of PS1-13cbe is similar to the spectral features of Type IIIn SNe such as SN1994Y (Filippenko 1997) that is used as an example here for the purpose of the comparison. Additionally, the peak luminosity of PS1-13cbe, $M_r \approx -19.4$, is not substantially brighter than the typical Type IIIn SNe, which have a broad peak luminosity range of $-18.5 \leq M_r \leq -17$ (e.g. Kiewe et al. 2011).

The Type-IIIn SN hypothesis is however disfavoured for the following reasons. First, the narrow emission-line ratios in Fig. 4 clearly identify the galaxy as a Seyfert, which increases the chances that this variability was caused by the existing AGN rather than an SN. Furthermore, the temperature of PS1-13cbe is roughly constant and it does not show any colour evolution, which is not consistent with the cooling of the ejecta typically seen in SNe. Additionally, the double hump behaviour seen in the light curves (Figs 2 and 7) of PS1-13cbe is not commonly observed in Type IIIn SNe (e.g. Kiewe et al. 2011; Taddia et al. 2013). While Type II SNe have been very rarely observed to exhibit multiple rebrightening bumps after the first peak (e.g. iPTF14hls and iPTF13z; Arcavi et al. 2017; Nyholm et al. 2017), the small fluctuations observed in the light curve of PS1-13cbe are not present in their light curves and the rise and rebrightening time-scales in the case of PS1-13cbe are much shorter in comparison.

Based on the reasons provided in this section, we disfavour the Type IIIn SN origin of PS1-13cbe, but this possibility cannot be completely ruled out.

4.2 PS1-13cbe as a TDE

Most of the optically detected TDEs show a lack of colour evolution and constant blackbody temperature, consistent with our observations of PS1-13cbe (Gezari et al. 2012; Chornock et al. 2013). Furthermore, broad emission lines such as H α , H β , and He II have been detected in the spectra of the TDEs and disappeared at later times (Van Velzen et al. 2011; Arcavi et al. 2014). Additionally, broad H α and H β lines are detected in the spectrum close to the time of the peak and either were not present (H β) or only weakly present (H α) in earlier spectra (SDSS) and disappear in the later spectra (OSMOS). Therefore, it is plausible that PS1-13cbe has a TDE origin. However, we do not have optical photometry data on the decline to check whether the light-curve decay at the predicted rate of $t^{-5/3}$ for TDEs (Rees 1988; Evans & Kochanek 1989). The lack of any X-ray observations at the time of the outburst is another limitation we face to investigate the TDE and SN scenarios.

As seen in Fig. 4, the host of PS1-13cbe is classified as a Seyfert galaxy, which points to the presence of a pre-existing AGN. However, TDEs can happen in AGN galaxies, and in fact it has been suggested that TDEs may prefer galaxies with pre-existing steady accretion to their central BH (Hills 1975; Blanchard et al. 2017) where the dense star formation clouds and the pre-existing accretion disc can increase the chance of the tidal encounter with the stars and reduce the relaxation time (Perets, Hopman & Alexander 2006; Blanchard et al. 2017). For example, the spectra of the hosts of the optical/UV TDE SDSS J0748 (Wang et al. 2011) and optical TDE candidate PS16dtm (Blanchard et al. 2017) show weak and narrow emission lines that might be the result of AGN presence in the core. Similar to them, the host of the TDE ASASSN-14li (Holoien et al. 2015) also shows traces of ongoing weak AGN activity at the centre (van Velzen et al. 2015; Alexander et al. 2016). Another possibility for brightening and rebrightening of nuclear transients could be repeat tidal stripping of stars (Ivanov & Chernyakova 2006; Campana et al. 2015; Komossa et al. 2016), although the time-scale for rebrightening in PS1-13cbe is very short.

However, we disfavour the TDE interpretation of PS1-13cbe because of the following reasons. The blackbody temperatures in optically selected TDEs typically range from $\sim 20\,000$ K (e.g. PS1-11af; Chornock et al. 2013) to $\sim 35\,000$ K and higher (e.g. ASASSN-14li; Holoien et al. 2015), while the continuum of PS1-13cbe at the time of the outburst is not as blue as a typical TDE and, as we show in Fig. 8, the inferred blackbody temperature of PS1-13cbe is no more than ~ 9000 K. Moreover, the He II $\lambda 4686$ line that is frequently seen in the spectra of TDEs (e.g. ASASSN-14li in Fig. 11) is not visible in the spectrum of PS1-13cbe that was taken close to the time of outburst. However, it is worth mentioning that there are TDE candidates that lack the presence of the He II $\lambda 4686$. Additionally, the rebrightening of PS1-13cbe by almost 75 per cent is not typically seen in TDEs. However, it is notable that the TDE candidate ASASSN-15lh showed rebrightening in the UV + 60 d after the peak (Dong et al. 2016; Leloudas et al. 2016; Margutti et al. 2017). The optical TDE candidate PS16dtm also showed dimming and rebrightening ~ 150 d after the beginning of the rise (Blanchard et al. 2017).

Furthermore, the light curves of the PS1-13cbe have noticeable fluctuations on few days time-scales (such as the one visible in gri_{p1} near -20 d in Fig. 2) that are inconsistent with the observed smooth optical light curves of most of the other known optically selected TDEs (e.g. Van Velzen et al. 2011; Gezari et al. 2012; Chornock et al. 2013; Arcavi et al. 2014; Holoien et al. 2014). However, noticeable fluctuations have been observed in the light curves of optical TDE candidate PS16dtm (Blanchard et al. 2017).

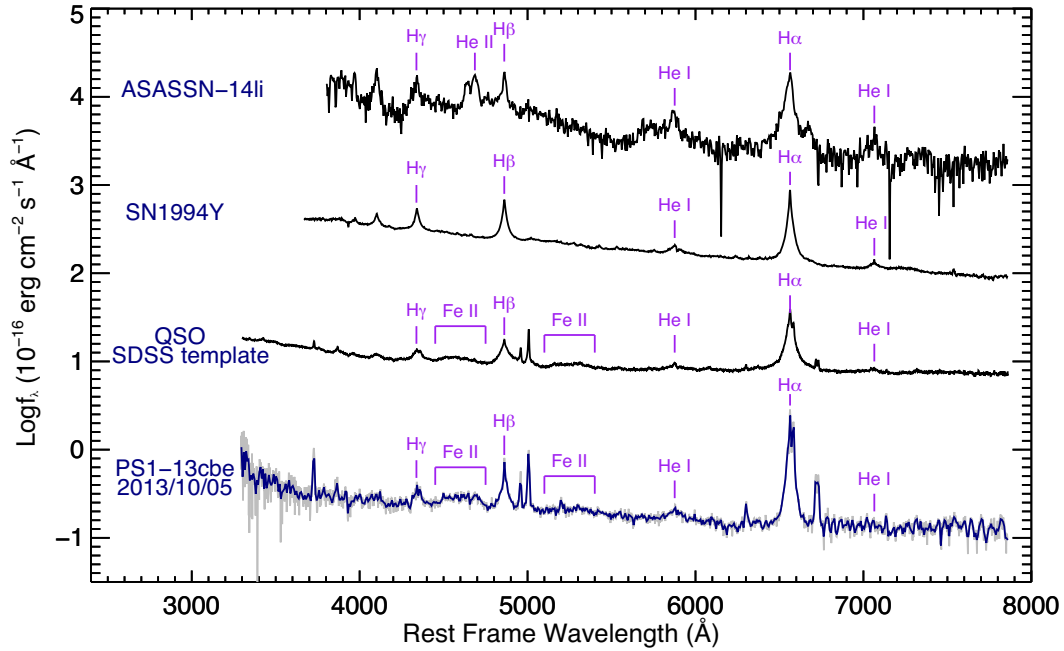


Figure 11. Optical spectrum of PS1-13cbe taken with LDSS3 during the outburst after subtracting the stellar continuum (blue). The spectra of the comparison objects include a QSO (SDSS QSO; Vanden Berk et al. 2001) template, a Type IIn SN (SN1994Y; Filippenko 1997), and a TDE (ASASSN-14li; Holoien et al. 2015); from bottom to top (black), the emission lines are labelled (purple).

The optical and spectral features of PS1-13cbe and the reasons provided in this section show that the TDE origin of PS1-13cbe is a possible but not a likely scenario.

4.3 PS1-13cbe as a ‘CL’ AGN

Recently, a new type of AGN variability was discovered in objects called ‘CL’ AGNs that show the appearance or disappearance of broad emission lines followed by an order of magnitude increase or decrease in the continuum and change type from Type 1 to Type 1.8, 1.9 or vice versa (e.g. Shappee et al. 2014; LaMassa et al. 2015; MacLeod et al. 2016; Runnoe et al. 2016; Gezari et al. 2017). This CL behaviour observed in some AGNs can be caused by at least three mechanisms. In the first scenario, variation of the obscuration when materials such as dust clouds outside of the BLR move in or out of the line of sight that can obscure or clear the view to the BLR (Elitzur 2012). Another mechanism can be variations of accretion rate that transforms the structure of the BLR. The AGN will transfer from Type 1 when the accretion rate is high and the broad lines are visible to a Type 2 when the accretion rate is low and the broad lines cannot exist or vice versa (Elitzur, Ho & Trump 2014). Furthermore, it has been suggested that transient events such as TDEs can cause this CL behaviour (Eracleous et al. 1995).

As shown in Figs 9 and 10, we only detected the presence of weak broad H α and no broad H β emission line in the spectrum taken by SDSS. However, the strong broad H α line and H β lines appeared at the time of the outburst that followed an observed increase in the flux and disappeared again in the spectra taken at later times. This shows that the AGN changed type from a Type 1.9/2 to a Type 1 and then to a Type 2 because no broad emission lines were detected in later observations.

We estimate the luminosity at 5100 Å (λ_{L5100}) based on our estimate that the non-stellar continuum contributes ≤ 10 per cent in the SDSS spectrum to be $\leq 0.15 \times 10^{43}$ erg s $^{-1}$ in quiescence.

Additionally, we measured the intrinsic 5100 Å (λ_{L5100}) luminosity at the peak of the outburst to be 1.16×10^{43} erg s $^{-1}$, which shows a factor of $\gtrsim 8$ increase in optical luminosity. Also, during this time the broad H α emission varied by a factor of ~ 4 in flux.

The observed luminosity changes and appearance and disappearance of the H α and H β lines can be caused by one of the three mentioned mechanisms that are discussed in more detail in the following sections.

4.3.1 Obscuration of the AGN

The CL behaviour seen in PS1-13cbe can be caused by intervening material that is located outside of the BLR and orbits on a Keplerian orbit that can obscure or give a clear view to the BLR by moving in or out of the line of sight. The bolometric luminosity of $\sim 9.4 \times 10^{43}$ erg s $^{-1}$ estimated at the time of outburst using bolometric corrections for unobscured AGNs is less than the bolometric luminosity of $\sim 1.6 \times 10^{44}$ erg s $^{-1}$ at the time of quiescence estimated from the narrow $\lambda 5007$ and mid-IR excess, which possibly indicates that the AGN is not fully unobscured at the peak of the outburst. In addition, the redder spectrum compared to the QSO template suggests such a scenario to be possible. However, we disfavour the changing obscuration scenario in the case of PS1-13cbe for the following reasons. First, we estimate the characteristic radius of the BLR using the R - L relation calibrated and presented by Bentz et al. (2013) to be $R_{\text{BLR}} \sim 11$ light days. Then, using the relation for crossing time presented by LaMassa et al. (2015), we estimate the crossing time for an obscuring object orbiting on a Keplerian orbit outside of BLR. In the most ideal case that minimizes the crossing time, the obscuring object should be at $r_{\text{orb}} \geq R_{\text{BLR}} = 11$ light days so that it can intercept a substantial amount of the broad Balmer flux from the BLR. Even in the extreme case of assuming $r_{\text{orb}} = R_{\text{BLR}}$, the crossing time for the obscuring object is ~ 23 yr. In a more realistic scenario where $r_{\text{orb}} \geq 3R_{\text{BLR}}$, the

crossing time is even higher. Not only are these time-scales too long to explain the CL behaviour of PS1-13cbe, but also the existence of intervening material with physical properties that can obscure the whole region of the continuum and the BLR at such radii is not obvious.

One of the possible candidates for obscuration is the torus that lies just outside of the BLR beyond the dust sublimation radius (e.g. Suganuma et al. 2006; Koshida et al. 2014; LaMassa et al. 2015). However, the sublimation radius is itself 4–5 times larger than the R_{BLR} where the crossing time-scale is ~ 29 yr, which is again too long to explain the observed event. Another possible obscuring scenario is that the dimming of the continuum itself promotes the formation of the dust that is able to cover the BLR. However, the time-scale for such dust formation with the gas density of $\sim 10^5 \text{ cm}^{-3}$ in the torus (e.g. Nenkova, Ivezić & Elitzur 2002) is $\sim 10^3$ yr (Draine 2009; LaMassa et al. 2015) that is far too long for this scenario to be true in the case of PS1-13cbe.

In addition, if the dust obscuration scenario is true, then the change in luminosity should follow the colour evolution and thus the colour evolution and luminosity change should be correlated. By contrast, there is no colour evolution while the luminosity is changing in the case of PS1-13cbe. We fit a linear regression model to luminosity versus $g - r$ colour index and found a slope of -0.01 ± 0.01 with a coefficient of determination $R^2 \sim 0.056$. These results confirm the lack of correlation between luminosity and $g - r$ colour index.

4.3.2 Tidal disruption events

As we mentioned in the Section 4.2, the lack of the colour evolution, constant blackbody temperature, and appearance/disappearance of the broad H α and H β lines suggest that the optical outburst and the appearance of the apparent blue continuum may have been powered by a TDE in the pre-existing AGN. Based on the reasons that we provided in the Section 4.2, we conclude that TDE origin of the outburst in PS1-13cbe is not favoured, but it cannot be ruled out completely.

4.3.3 Accretion disc instabilities

In the light curves of PS1-13cbe shown in Fig. 2, there are small undulations that can be seen in all of the filters (e.g. near -20 d). The amplitudes of these changes are consistent with the variability observed in AGNs (e.g. MacLeod et al. 2012) and point to fluctuations in ongoing accretion activity.

It has been shown that in AGNs the optical/UV emission is generated in the accretion disc, with two possible classes of models for the propagation of fluctuations. One is that the locally generated viscous perturbations can produce local blackbody emission (e.g. Krolik 1999; Liu et al. 2008). In the case of these so-called ‘outside-in’ variations that are produced by changes in accretion rate, the accretion flow fluctuations propagating inward and across the accretion disc first affect the optical region located at outer radii and then affect the UV- and X-ray-emitting regions. Another origin can be the reprocessing of the UV or X-rays (e.g. Krolik et al. 1991; Cackett, Horne & Winkler 2007; Liu et al. 2008). In this case, the X-rays from the central source irradiate the disc and produce ‘inside-out’ variations from short to long wavelengths (Shappee et al. 2013; LaMassa et al. 2015)

The time-scale over which the accretion changes happen that might produce ‘outside-in’ variations is known as the inflow time-scale. More accurately, changes in the accretion responsible for the

‘outside-in’ variations happen on the inflow time-scale, which is the time it takes a parcel of gas in a given radius in the accretion disc to radially move to the centre. Assuming the optical continuum emission radius of $R \approx 200 r_{\text{S}}$ (e.g. Morgan et al. 2010; Fausnaugh et al. 2016) and using the relationship between radius and inflow time-scale presented by LaMassa et al. (2015), we calculate the inflow time-scale to be $t_{\text{infl}} \sim 10^6$ yr, which is much longer than the observed change in the continuum flux of PS1-13cbe.

However, it is notable that the optical continuum originates in a part of the disc where the radius is an order of magnitude larger than the UV-emitting region, which results in a several thousand times larger inflow time-scale than for the UV-emitting region (LaMassa et al. 2015). Thus, we conclude that the rapid continuum flux change in PS1-13cbe is too short to be generated by outside-in variations (perturbations in a given radius of the disc that propagate radially inward), but might be more characteristic of a disturbance in the inner accretion flow that propagates outward.

Assuming a standard thin disc model (Shakura & Sunyaev 1973) with an optically thick and geometrically thin accretion disc, we calculate the dynamical (orbital) time-scale $t_{\text{dyn}} = 1/\Omega$ of the SMBH, where $\Omega = \sqrt{\frac{GM}{R^3}}$. We can rewrite the dynamical time-scale to be $t_{\text{dyn}} = 2^{3/2} \frac{GM}{c^3} \left(\frac{R}{r_{\text{S}}}\right)^{3/2}$, where c is the speed of light and $r_{\text{S}} = \frac{2GM}{c^2}$ is the Schwarzschild radius of the central BH. The dynamical time-scale around an SMBH with a mass of $2.2 \times 10^7 M_{\odot}$ can be written as $t_{\text{dyn}} \approx 310 \left(\frac{R}{r_{\text{S}}}\right)^{3/2}$ s. Assuming an optical emission distance of $R \approx 200 r_{\text{S}}$ (e.g. Morgan et al. 2010; Fausnaugh et al. 2016), we calculate the dynamical time-scales of ≈ 10 d. Then, using $t_{\text{th}} = \alpha^{-1} t_{\text{dyn}}$ we calculate thermal time-scale to be ≈ 99 d. We note that these values are not strongly dependent on the uncertainties in the BH mass for this object, so the ordering of time-scales is robust.

Among all of the calculated time-scales, only the thermal time-scale of ~ 99 d is reasonably similar to the observed time-scale of ~ 70 d in the case of PS1-13cbe and suggests another possible scenario where reprocessing of the UV or X-rays can produce the optical variations. In this case, an increase in the X-rays that originate in the smaller hot corona that is closer to the central BH can heat the inner part of the accretion disc first, move outward, and generate inside-out variations by irradiating the disc and driving an increase in the blue and then red emission. This scenario has been observed and well studied in NGC 2617 (Shappee et al. 2013; Oknyansky et al. 2017). Shappee et al. (2013) detected the variability first in X-rays and then with time lags in UV and NIR and concluded that the observed continuum flux variability resulted from inside-out variations. In another example, NGC 4151, it was also observed that X-ray variability drove UV–optical variability (Edelson et al. 2017).

4.4 Comparison to other CL AGNs

PS1-13cbe is one of the few CL AGNs that has been observed during the turn-on phase (Cohen et al. 1986; Storchi-Bergmann et al. 1993; Aretxaga et al. 1999; Eracleous & Halpern 2001; Shappee et al. 2014; Gezari et al. 2017) by suddenly demonstrating the appearance of broad H α and H β emission lines. The CL behaviour has been observed in other candidates where the broad lines appeared or disappeared in spectra taken a couple of years to decades apart (e.g. LaMassa et al. 2015; Runnoe et al. 2016; MacLeod et al. 2018). By contrast, in PS1-13cbe the outburst time-scale is very short. PS1-13cbe ‘turned on’ in only 70 d and the broad lines were observed in a spectrum taken 57 d after the peak of the outburst. Furthermore, the broad lines disappeared before 2 yr after the time

of the peak, which is again very short, and they never reappeared in later spectra (see Fig. 3). However, we should note that by ‘turn-on’ we refer to brightening of a pre-existing AGN, but the presence of the strong narrow emission lines with a Seyfert 2 spectrum implies that narrow-line region was exposed to AGN accretion activity in the recent past.

Gezari et al. (2017) also presented the CL quasar iPTF 16bco that had a ‘turn-on’ time-scale of ≤ 1 yr, which is very short for a BH with $M_{\text{BH}} \sim 10^8 M_{\odot}$ compared to others. PS1-13cbe and iPTF 16bco are the only CLs that demonstrate extremely short turn-on time-scales that push the limit of the accretion disc theory. One more interesting fact about PS1-13cbe is that the light curves showed a double peak behaviour observed in all of the optical bands (see Fig. 2). This behaviour was also observed in the X-rays/UV in the case of NGC 2617 (Shappee et al. 2014), in the UV/optical in the case of the ASASSN-15lh TDE candidate (Dong et al. 2016; Leloudas et al. 2016; Margutti et al. 2017), and in the optical band in the case of the PS16dtm TDE candidate (Blanchard et al. 2017).

5 CONCLUSIONS

We present a transient event that was discovered in the PS1/MDS survey, PS1-13cbe, at redshift $z = 0.12355$. The outburst happened in the nucleus of a galaxy that is classified as a Seyfert 2 (see Fig. 4) using the SDSS archival data that were taken a decade before the outburst. At the time of the outburst, the galaxy changed type to a Seyfert 1 as broad $H\alpha$ and $H\beta$ appeared and the continuum brightened in the spectrum taken with LDSS3 + 57 d after the peak and then changed its type back to a Seyfert 2 as the broad $H\alpha$ and $H\beta$ disappeared in the spectrum taken with OSMOS 2 yr later and did not reappear in spectra taken 3 and 4 yr after the outburst. The optical photometry shows that the continuum flux increased by a factor of ~ 8 on a time-scale of ~ 70 d and declined for next ~ 50 d and then rose again over the course of the next ~ 50 d.

Observational evidence presented in this work argues against the Type II_n SN and TDE interpretations. The constant colour evolution and blackbody temperature during the outburst and also the presence of a pre-existing AGN disfavour the SN Type II_n scenario. As mentioned, TDEs have been observed in the galaxies with pre-existing AGNs (e.g. SDSS J0748; Wang et al. 2011); however, the lack of a broad He II $\lambda 4686$ emission line, low blackbody temperature at the time of peak, a light curve that has small fluctuations, and unusual rebrightening by 75 per cent are inconsistent with properties of known TDEs.

We conclude that PS1-13cbe is a CL AGN that has been powered by instabilities in the accretion disc. We argued against the obscuration scenario and TDE origin of these accretion disc instabilities by showing that the crossing and viscous time-scales are longer than the time-scale observed in the case of PS1-13cbe. Furthermore, we also argued against outside-in variations by calculating the inflow time-scale that is too long to explain the observed time-scale here.

We also conclude that the thermal instabilities in the accretion disc are most likely the source of the outburst and CL behaviour. These thermal instabilities may have caused inside-out variations that have generated the observed optical variability in the light curves of PS1-13cbe. One very interesting point about PS1-13cbe is that the observed turn-on time-scale pushes the limits of viscous accretion disc theory that predicts much longer time-scales and it might be one of the CLs that have shown the most rapid change of the state (iPTF 16bco; Gezari et al. 2017) compared to the other CLs.

Other CLs have been observed over a timespan of years and sometimes decades apart; however, the short time-scale observed here suggests that other candidates may have been through these

short time-scale outbursts. Therefore, more frequent observations with a higher cadence and multiwavelength coverage to overcome limitations such as the one we faced here with the lack of X-ray observations at the time of outburst will provide us more insight to better understand the CL behaviour of AGNs.

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