

A fast rising tidal disruption event from a candidate intermediate mass black hole

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Massive black holes (BHs) at the centres of massive galaxies are ubiquitous. The population of BHs within dwarf galaxies, on the other hand, is evasive. Dwarf galaxies are thought to harbour BHs with proportionally small masses, including intermediate mass BHs, with masses $10^2 < M_{BH} < 10^6 M_{\odot}$. Identification of these systems has historically relied upon the detection of light emitted from accreting gaseous discs close to the BHs. Without this light, they are difficult to detect. Tidal disruption events (TDEs), the luminous flares produced when a star strays close to a BH and is shredded, are a direct way to probe massive BHs. The rise times of these flares theoretically correlate with the BH mass. Here we present AT 2020neh, a fast rising TDE candidate, hosted by a dwarf galaxy. AT 2020neh can be described by the tidal disruption of a main sequence star by a $10^{4.7} - 10^{5.9} M_{\odot}$ BH. We find the observable rate of fast rising nuclear transients like AT 2020neh to be rare, at $\lesssim 2 \times 10^{-8}$ events $\text{Mpc}^{-3} \text{ yr}^{-1}$. Finding non-accreting BHs in dwarf galaxies is important to determine how prevalent BHs are within these galaxies, and constrain models of BH formation. AT 2020neh-like events may provide a galaxy-independent method of measuring IMBH masses.

In Figure 1 we present the nuclear transient, AT 2020neh. AT 2020neh was first reported by the Zwicky Transient Facility (ZTF; 1) on 19th June 2020 at right ascension $15^h 21^m 20.07^s$ and declination $+14^\circ 04' 10.74''$ (J2000), and was confirmed with Young Supernova Experiment data (YSE; 2), which showed an initial earlier detection on 17th June 2020. The location of the transient, confirmed in late time imaging from the Hubble Space Telescope (Figure 1), is coincident with the nucleus of the galaxy, lying within $0.1''$ of the centre. Host-galaxy spectral lines constrain the redshift of the event to $z = 0.062$ (~ 280 Mpc). AT 2020neh reached peak brightness on 1st July

2020, and was monitored with multi-wavelength follow-up observations for over 400 days from peak in the rest frame (for details of the follow-up campaign, see Methods). The full ultraviolet and optical light curves for AT 2020neh are shown in Extended Data Figure 1.

We present our spectroscopic follow-up observations of AT 2020neh in Figure 2. The classification spectrum, obtained using the Nordic Optical Telescope on 25th June 2020, 6 days before maximum light, shows a strong blue continuum with a clearly blended helium II $\lambda 4685$ and nitrogen III $\lambda 4640$ emission feature, and no traces of hydrogen. This blended emission feature has been observed for several optical TDEs (3, 4, 5, 6, 7), and is attributed to a fluorescence mechanism requiring both a high-energy radiation source and a high gas density (8). Given the nuclear location of the transient (Figure 1), we interpret these features under a TDE classification for the transient AT 2020neh. The spectra become featureless after maximum light, evolving to gradually reveal a broad hydrogen, $H\alpha$, emission line at +36 d (and later in $H\beta$ too). This $H\alpha$ emission dominates the late-time spectra of AT 2020neh, exhibiting an asymmetric profile which is blueshifted with respect to the rest frame by $\sim 4000 \text{ km s}^{-1}$ (see Extended Data Table 1). The profile of this emission is consistent with emission lines arising from optically thick outflowing material (9), which has been seen in several other TDEs (e.g. 7, 10, 11, 12). The lack of elements heavier than hydrogen within the late time ($>200 \text{ d}$) spectra is consistent with a TDE classification, as these elements would only be expected if the event arose from a stellar explosion (13).

Only a dozen TDEs have optical light curves with sufficient data coverage at early times to confidently determine the time taken for the transient to reach maximum light (see 14). In Figure 3

we show the distribution of their rise times and luminosities, alongside those of AT 2020neh. The constraining non-detections from frequent YSE monitoring prior to first detection of the transient, and the depth of the YSE imaging, result in an exceptionally well constrained rise time for this event. With information on the evolution of AT 2020neh down to 3% of its maximum light, we measure a rise time from initial detection to g -band peak of only 13.2 ± 1.0 days in the rest frame. To date, this is the fastest measured rise time for a TDE, on average a factor of $2.4^{+3.0}_{-1.5}$ times faster than others with pre-max light curve coverage. AT 2020neh attained a peak bolometric luminosity of $(4.2 \pm 0.1) \times 10^{43} \text{ erg s}^{-1}$. Whilst this luminosity alone is not unprecedented amongst TDEs, when taken into consideration with its short rise time, it places AT 2020neh on the periphery of the known nuclear transient luminosity-rise parameter space, being brighter than other confirmed TDEs with short rise times. This unique location places AT 2020neh between TDEs and another class of transients - namely ‘Fast and Blue Optical Transients’ (FBOTs) (e.g. 15, 16, 17). Despite this similarity in rise time, AT2020neh shows significant differences in both its spectroscopic properties and its photometric evolution from those of FBOTs (see Methods), which set it apart from this class. We find that the post-maximum evolution of AT 2020neh is typical of other TDEs, being well described by a power-law decline slope of $\alpha = 1.44 \pm 0.19$. This is consistent with the theoretical $-5/3$ slope expected from transients powered by fallback accretion (18).

The host galaxy of AT 2020neh, SDSSJ152120.07+140410.5, is unusual amongst the population of TDE host galaxies (see Methods). The galaxy is blue in color and a pre-explosion SDSS spectrum of the host galaxy shows that it is star forming (see Extended Data Figure 4). However, the galaxy also has a high Sérsic index and a high surface density concentration of stellar mass

relative to field galaxies. This increases the number of stars capable of being disrupted, which has been seen within other TDE host galaxies (19, 20, 21). When we measure the stellar mass of SDSSJ152120.07+140410.5, we find it to be $\log(M_{\star}/M_{\odot}) = 9.57 \pm 0.20$. This mass is consistent with the masses of dwarf galaxies, and is about the same as the mass of the Large Magellanic Cloud. Scaling relations between galaxy stellar mass and BH mass (derived from more massive galaxy populations, (22)) predict that for such small galaxies, we expect correspondingly low-mass BHs. Direct evidence for the presence of BHs in low-mass galaxies however, is scarce (see 23). These systems are typically faint, and the gravitational sphere of influence for low-mass BHs is predicted to be small, making them difficult to resolve in observations of galaxies outside of the Local Group. Thus the occupation fraction of BHs at the low mass end of the galaxy stellar mass regime remains observationally unconstrained (24). The detection of AT 2020neh thus indicates the presence of a BH in a dwarf galaxy, from which we can begin to explore the properties of the BH.

The unique location of AT 2020neh in Figure 3 implies a relative scarcity of similar events like this amongst the TDE population. Indeed, we estimate the observable rate of fast rising TDEs, like AT 2020neh to be $\lesssim 2 \times 10^{-8} \text{ Mpc}^{-3} \text{ yr}^{-1}$ at $z = 0.27$, the detection limit of the YSE survey (see Methods). This is approximately one twenty-fifth of the ‘normal’ TDE rate (25). The relatively low rate of fast TDEs may be explained through the mechanics of the BH-stellar encounter. For low ($< 10^6 M_{\odot}$) mass BHs, the event horizon of the BH is much smaller than the tidal radius required to disrupt a star of average mass. Therefore in order for the event to be observed as a ‘classical TDE’, one whose luminosity closely follows the rate at which material falls onto the BH

(the ‘fallback rate’), a plunging encounter is required. Such an encounter allows the material to circularise quickly enough for the event to be observable (26), as found when modelling AT 2020neh (see Methods). Events with more shallow, grazing encounters are unlikely to circularise their debris into an accretion disc on timescales shorter than the timescale of peak fallback accretion. This is a consequence of weaker general relativistic effects around smaller BHs. These encounters are thought to produce less luminous transients with irregular light curves which are unlikely to be observable (27). We estimate the peak luminosity of AT 2020neh to exceed the maximum (Eddington) luminosity at which the BH can radiate by a factor of $\sim(2 - 3) \times L_{\text{Edd}}$ for its measured BH mass range (28). This is in agreement with theoretical predictions, as observable TDEs around lower mass BHs are also likely to be ‘super-Eddington’ flares, as a result of their predicted high fallback rates (27).

The properties of the TDE light curve can potentially be used to probe the BH mass (29), which could provide a measurement independent of assumptions about the host galaxy. The rise time of a TDE, Δt , which is the time taken between disruption of the star to peak luminosity of the event, theoretically correlates with the BH mass. This is because the luminosity of the transient is expected to follow the fallback rate of the stellar debris, with a relationship $\Delta t \propto M_{\text{BH}}^{0.5}$ (29, see Methods for modelling details). Fitting the multiband UV-optical light curve of AT 2020neh (Extended Data Figure 6) we find $\log M_{\text{BH}}/M_{\odot} = 5.5^{+0.4}_{-0.3}$. We note that the physical origins of the early optical emission in TDEs is unknown, so this approach to BH mass estimation may not be applicable to all events. We assess the reliability of this measurement with two galaxy-BH scaling relationships. The $M_{\star} - M_{\text{BH}}$ scaling relation (22) predicts a BH mass of $\log M_{\text{BH}}/M_{\odot} = 5.9 \pm 0.2$.

We use a late-time high-resolution spectrum of the TDE to measure the velocity dispersion (σ) of the host galaxy. We measure $\sigma = 39 \pm 13 \text{ km s}^{-1}$, which using an $M_{\text{BH}} - \sigma$ relation (30) provides a BH mass of $\log M_{\text{BH}}/M_{\odot} = 4.8^{+0.5}_{-0.9}$. These are both consistent with the mass estimated from the rise of the light curve. Our constraints on the mass range of the BH, $4.7 < \log M_{\text{BH}}/M_{\odot} < 5.9$, place it within the domain of ‘intermediate mass BHs’ (IMBHs), whose masses span the gap between stellar-mass and supermassive BH populations ($2 \lesssim \log M_{\text{BH}}/M_{\odot} \lesssim 6$), but for which evidence of a firm population has been difficult to obtain (31).

The massive BHs ($M_{\text{BH}} \gtrsim 10^9 M_{\odot}$) we observe in the hearts of galaxies in the local Universe (32) must originate from less massive BHs which have grown through mergers or accretion of surrounding material. How this putative ‘seed’ population of less massive BHs forms is unclear. Possible formation mechanisms include hierarchical mergers of stellar-mass BHs (33), core-collapse of exceptionally massive stars in the early Universe (34), and the direct collapse of massive gas clouds (35). Measuring the low-mass ends of the BH mass function and BH-galaxy scaling relationships is important for distinguishing between these scenarios, as each model is predicted to influence the slope of these relationships differently (31). Identifying BHs in dwarf galaxies and measuring their masses is generally difficult (23, 36, 37, 38) due to their intrinsically low luminosity and smaller gravitational influence. Typically, signatures of BH accretion (an Active Galactic Nucleus, ‘AGN’) are required to reliably confirm the presence of a BH in a dwarf galaxy (e.g. 39, 40, 41, 42). However, the majority of BHs are not active. Fast-rising optical TDE candidates such as AT 2020neh therefore may offer an opportunity to find and study non-active BHs in dwarf galaxies.

In Figure 4 we display the location of AT 2020neh on two commonly used BH-galaxy scaling relations. AT 2020neh is the first candidate optical TDE from an IMBH in a dwarf galaxy. Moreover, its host galaxy is one of only a small number of dwarf galaxies which has a BH mass estimate independent of galaxy scaling relationships. At present, most galaxies in the low-stellar mass/low-velocity dispersion regions of BH scaling relations are low-luminosity AGN, and therefore not representative of the quiescent dwarf galaxy population. A handful of X-ray detected transients in dwarf galaxies have also had a IMBH-TDE origin proposed (43, 44, 45), for which the BH mass estimates have been derived from galaxy-scaling relationships from fitting of the X-ray spectrum with disc models. AT 2020neh represents the first of a population of optically detected transients whose properties may allow us to explore the low-mass end of BH-scaling relations in a complementary way. The relative rate of fast-TDEs to normal-TDEs implies that other events like AT 2020neh should be more common amongst the TDE population. Early detection of future fast TDEs within deep, high-cadenced data sets, like the early YSE detection of AT 2020neh, will generate the samples of events with constraining data sets needed to test the reliability of estimating BH masses from rise-time measurements. The properties of AT 2020neh will form the baseline from which targeted observing strategies can be designed to ensure maximum scientific gain from the discovery of fast TDEs in current and future surveys. We estimate that YSE will observe another 5-6 similar events over its lifetime, each with the necessary light curve data to constrain the rise time.

Methods Summary

We describe the data, methods and theoretical calculations used within this work. We outline the different photometric and spectroscopic data sets used and describe the reduction and analysis techniques adopted. We discuss the interpretation of the transient as a TDE against other spectroscopic classes, and provide details of the localization of AT 2020neh within its host galaxy. We present the analysis used to determine the host-galaxy properties and the different methods used to infer the BH mass. Finally, we present our methodology for the determination of the rate of AT 2020neh-like events, and estimate the number of similar events which could be identified in current and next-generation surveys. Throughout this work we assume a standard Λ CDM cosmology with $H_0=71 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M=0.27$ and $\Omega_{vac}=0.73$.

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Author contributions

C.R.A. led the overall project and analysis, and wrote the majority of the paper. They are also PI of the NOT and Gemini programs used to collect data. V.F.B. performed the analysis to searched for previous variability of host galaxy, wrote text, made the $M-\sigma$ figure, and contributed to discussions regarding the link between the BH and host galaxy. B.M. performed the MOSFiT light curve analysis, made the MOSFiT figure and wrote text. R.J.F. reduced the HST data and observed for the Keck nights. They are PI of Keck, Lick, and Hubble programs used to collect data. They also wrote text, contributed to contributed to discussions regarding interpretation of the object and provided feedback on the manuscript. E.R.-R. contributed to discussions regarding the theoretical interpretation of the event. S.I.R. helped to perform the pPXF fitting of the host galaxy features and contributed to discussions. K.D.F. contributed to discussions regarding the nature of host galaxy

and provided extensive feedback on manuscript drafts. K.A. triggered, reduced and analysed the *Swift* data used, contributed to discussions of results and observations. They also wrote text for the paper and provided comments on the manuscript. H.P. performed part the rate analysis of fast TDEs, contributed to discussions regarding the interpretation of the event and provided feedback on manuscript drafts. They also performed vetting of candidates within the YSE survey. C.G. performed spectral line profile analysis of the H α emission, contributed to discussions and provided feedback on manuscript drafts. J.H. contributed to discussions and provided extensive feedback on manuscript drafts. M.R.D. contributed to discussions and performed initial analysis regarding the rate of fast tidal disruption events within YSE. K.D.A. triggered and reduced radio observations with the VLA, and contributed to the interpretation of the resulting upper limits. G.D. reduced the GMOS spectra. T.H. reduced data, observed and submitted observing proposals for the event. D.O.J. reduced the YSE data for the event and performed PS1 operations for the survey. A.R. analysed and helped to interpret the forced YSE photometry of the event. M.R.S. reduced the LRIS and KAST spectra. K.T. provided manuscript comments and observed with Keck. G.T. observed and reduced the DEIMOS spectrum from Keck. C. M.C., L. DeM. N.E. and A.G. provided extensive feedback for the manuscript as a junior review panel. L.I., S.T., V.A.V., Y.Z. also provided comments on the paper. N.A., C.C., N.K. and R.J.W. performed vetting of candidates within the YSE survey. D.A.C. wrote the collaboration software platform YSE-PZ and support it and the server it runs on. T.J.L.de B., K.C.C., C.C.L., E.A.M. and C.R-B. perform PS1 operations, including supporting the Pan-STARRS IPP which provides the initial astrometry and photometry. C.R.A., R.J.F., S.I.R., K.A., H.P., J.H., C.G., L.I., N.A., C.C. and R.W. all performed vetting of candidates

within the YSE survey.

Methods

Data

Optical Photometry The optical photometry of AT 2020neh is obtained by the Young Supernova Experiment (YSE) sky survey (2) with the 1.8m Pan-STARRS telescope (PS1). PS1 is mounted with a 1.4 Gigapixel camera (48) to image the sky in the g , r , i , and z filters. The data are downloaded, processed and archived using the Image Processing Pipeline (IPP) at the University of Hawaii’s Institute for Astronomy (49). Images from the PS1 3π survey are used as references for template subtraction, with each reference image convolved to match the point spread function (PSF) of the nightly observations, before passing through the Transient Science Server at Queens University Belfast (50) to identify new events. The YSE photometric pipeline is based on PHOTPIPE (51). Forced PSF photometry is performed for each transient, using a flux weighted centroid matching the PSF at the transient location.

The field in which AT 2020neh is located was monitored by YSE for 3 months prior to the first detection of the transient, with non-detections at 18 epochs over this period, in which no light from the transient is observed. These data provide strong constraints upon the explosion epoch down to limiting magnitudes of typically $m \approx 21.5$ mag in the g , r and i bands and $m \approx 20.5$ mag in z . Additional g - and r -band photometry of AT 2020neh is taken from the public Zwicky Transient Facility (ZTF, 52, 53) data stream, with observational coverage from 19 June 2020 to 04 August 2020 (-12 to $+35$ days in the rest frame phase).

Optical Spectroscopy Spectra were obtained using the instruments and observational set-ups listed in Extended Data Table 2. The ALFOSC, Kast and LRIS spectra were reduced using custom made pipelines and standard routines within IRAF. The GMOS spectra were processed using the Gemini IRAF package. The DEIMOS spectrum was processed with the PyPeIt software package (54). All calibrations and correction procedures are performed after the basic pipeline reduction using custom python programs. Spectra are corrected for an average Galactic extinction along the line of sight to the transient of $E(B - V) = 0.038$ mag and $R_V = 3.1$ based on the dust maps of (55). We use a pre-transient Sloan Digital Sky Survey (SDSS; 56) spectrum of the host galaxy to correct for the host-galaxy contribution to the spectra. We color correct both transient and host-galaxy spectra using the technique of (57) to the available g,r,i,z photometry from PS1 to correct for slit/fibre losses. For the low-resolution ALFOSC and Kast spectra, we convolve this host-galaxy spectrum to the resolution of these instruments before subtraction. For higher-resolution spectra, we create models of the host-galaxy emission lines based on measurements from the SDSS spectrum and subtract these models from the science spectra. All line measurements are performed using the `specutils` package in python¹. We note that several narrow stellar absorption features with widths smaller than the instrumental resolution of the SDSS spectrograph still persist within our host-galaxy subtracted spectra (a consequence of the low velocity dispersion of the host galaxy - see below).

Swift Observations We requested, and were awarded, target-of-opportunity (ToO) observations from the Neil Gehrels Swift Gamma-ray Burst Mission (*Swift*) UltraViolet and Optical Tele-

¹<https://specutils.readthedocs.io/en/stable/index.html>

scope (UVOT) and X-ray Telescope (XRT). AT 2020neh was monitored with *Swift* over two epochs whilst the transient is active; from 01 Jul 2020 to 17 Jul 2020, and from 05 Aug 2020 to 06 Sept 2020 with an approximate 2 day cadence. Final *Swift* observations were also obtained between 13 January 2021 to 27 January 2021 and averaged to estimate the host-galaxy level for subtraction. To obtain the UVOT photometry, we used the task `UVOTSOURCE` with source radii of 5.0 '' and background radii of 40.0 ''. The transient is clearly detected with UVOT during the first two epochs. The host-galaxy subtracted UVOT light curve is presented in Extended Data Figure 1.

XRT was operated in the Photon Counting mode for all observations. We reprocessed the data with the task `XRTPIPELINE` version 0.13.2, using standard filters, screen and recent calibration files. Using a source region centered on the location of AT 2020neh with a radius of 49 '' and a 150 '' radius source free background region centered at $15^h21^m04.77^s$, $+13^\circ59'37.78''$, we detect no significant X-ray emission arising from the source. To constrain any X-ray emission, we merge all 37 Swift XRT observations of AT 2020neh using the task `XSELECT`. We derive a 3σ upper limit to the 0.3-10.0 keV count rate of 0.002 counts s^{-1} . Assuming an absorbed powerlaw model with a column density of $2.7 \times 10^{20} \text{ cm}^{-2}$ (58) and $\Gamma = 2.7$ (similar to that of other X-ray bright TDEs (e.g., 59)), redshifted to the location of the host galaxy, we find an 3σ upper limit to the unabsorbed X-ray luminosity of $4.5 \times 10^{41} \text{ erg s}^{-1}$. This faint X-ray luminosity is consistent with other previously observed TDEs (59) and suggests the source does not harbour a strong AGN component, congruous with the composite location of the host galaxy in the BPT diagram (Extended Data Figure 4).

Radio Observations AT 2020neh was observed twice during its evolution with the Very Large Array (VLA) under program VLA/20B-377 (PI: Alexander). The first observation was conducted

on 30 Jun 2020 (-1 days from peak in the TDE restframe) at 15 GHz. The source was not detected with a 3σ upper limit of $18 \mu\text{Jy}$. The second observation on 31 Dec 2020 (+172 days restframe) at 6 GHz also resulted in a non-detection, with a 3σ upper limit of $16 \mu\text{Jy}$. These limits are consistent with a lack of a relativistic jet (60), and further support the conclusion that the host galaxy does not harbour an obvious AGN (see Host Galaxy Properties).

HST Observations We observed AT 2020neh on 16 Sept 2021 with the Wide Field Camera 3 on the *Hubble Space Telescope* (HST) under program SNAP-16239 (PI:Foley). AT 2020neh was imaged in F225W and F275W for a total exposure time of 780 and 710 s, respectively. Two images were taken in each band to reject cosmic rays. The data were processed through the STScI data reduction pipeline, including basic processing, calibration, and drizzling.

AT 2020neh is clearly detected in the *HST* images at the centre of its host galaxy surrounded by a circumnuclear ring with a projected radius of $0.35\text{--}0.7''$, corresponding to physical distances of $0.45\text{--}0.9$ kpc at $z = 0.062$. We perform photometry using the automatic detection and extraction package, Source Extractor (SExtractor, 61), applying a surface brightness signal-to-noise cut of two per pixel to include faint surface brightness features and adjusting the extraction parameters to separate the TDE from the star forming ring. Zeropoints for each filter were taken from the STScI WFC3 handbook (62). We measure $m_{\text{F225W}} = 22.059 \pm 0.022$ and $m_{\text{F275W}} = 21.790 \pm 0.019$.

Transient Classification

The photometric properties of AT 2020neh make it exceptional amongst the nuclear transient population, with a fast rise and luminous peak, which require careful classification. In particular it

is important to distinguish this event from hydrogen rich core collapse SNe (SNe II), as the evolutionary timescales and hydrogen spectral features are similar to this class. It is also important to establish whether AT 2020neh could be classified as an FBOT event. Below we present the evidence for a TDE origin for AT 2020neh.

Spectroscopic Behaviour The dominant feature present within the NOT spectrum taken pre-maximum light, is a strong blended He II and N III emission feature around 4660 Å. This feature is no longer detectable within the first post-max spectrum obtained at +9d with GMOS. Such short-lived features have been observed within samples of young SNe II, where the high-energy ultraviolet emission which occurs during shockbreak-out briefly ionises any surrounding circumstellar material, recombining to produce strong emission lines (e.g., 63, also see Extended Data Figure 2). SNe which exhibit these “flash ionisation” features are typically accompanied by Balmer emission lines, which we do not observe with AT 2020neh at this epoch (all Balmer features observed in the NOT spectrum are consistent with the SDSS spectrum of the host galaxy). Based on the velocities observed for the He II/N III emission ($950 \pm 160 \text{ km s}^{-1}$), we should have observed any flash ionised Balmer emission within this early spectrum.

The later spectroscopic evolution of AT 2020neh also does not follow the canonical behaviour of a SN II. We only begin to observe $H\alpha$ emission at later epochs (> 37 days from peak), when it presents a broad, boxy blueshifted emission profile with no accompanying absorption. Whilst there is diversity in the $H\alpha$ features present within SN II spectra (64, 65), $H\alpha$ nominally takes on a P-Cygni profile for these events, due to the expanding, optically thick material ejected from the progenitor. For AT 2020neh to be a SN II, the lack of P-Cygni signature in its $H\alpha$ emission would

require either the photosphere to be very small compared to the expanding material, or there to be optically thin material along the line of sight masking the photosphere. The first scenario is rare, seen only in a few SNe-II at very early times (64). The second scenario requires the observed $H\alpha$ emission to be produced via interaction (as for SNe IIn), for which narrow we would expect to see very narrow features ($\sim 200 \text{ km s}^{-1}$). We do not observe this narrow emission in AT 2020neh. Though blueshifted Balmer features have been observed within some SNe II, they typically occur at much smaller velocity shifts (population mean 2000 km s^{-1} , (66)) compared to the $\sim 4000 \text{ km s}^{-1}$ shift observed within AT 2020neh. SNe II blueshifts also evolve with time, disappearing by the nebular phase. The $H\alpha$ line remains blueshifted until late times, and does not evolve significantly during the later states of its evolution. Finally, the late time ($>200 \text{ day}$) spectra of AT 2020neh do not show the forbidden lines [Ca II], [O I] and [Fe II] traditionally observed during the nebular phase in SNe II (13, 65).

There are few FBOTs with spectroscopic data sets sufficient to determine what the typical spectroscopic features of this class are. Those which do generally exhibit hot, featureless spectra (15, 17, 67). The luminous and local AT 2018cow (16, 68) is the only FBOT with sufficient spectroscopic data to make any meaningful comparisons. Post-peak $H\alpha$ emission has also been observed within this event, however it is significantly narrower than the $H\alpha$ seen in AT 2020neh at similar phase (68), even when accounting for the narrower component we see observe at much later epochs (which exhibits velocities of order 2000 km s^{-1}).

Though not typical of optically selected TDEs (25, 69), these spectroscopic properties can all be interpreted within a TDE framework. We attribute the blended He II and N III early emission

feature to Bowen fluorescence (Extended Data Figure 2), which has been observed within several TDEs (4, 7). Blue-shifted, boxy Balmer emission profiles have also been observed within some TDEs (e.g. 11), and have been shown to result from strongly irradiated, outflowing, optically thick material from the system (9). Though the widths of the emission lines observed in AT2020neh are narrower than those seen in other TDEs (25), these features are viewing angle dependent, and therefore could be a result of a system with low inclination (70). The lack of nebular phase features is also consistent with a non-supernova origin.

Photometric Behaviour Though the fast rise of AT 2020neh does coincide with the distribution of rise times observed for SNe II (71), it is significantly more luminous, with a peak luminosity four times brighter than the upper end of the SN II luminosity function (72). To construct the bolometric light curve of AT 2020neh, we interpolate the available photometry (corrected for foreground extinction) in each band using gaussian processes, a non-parametric interpolation method which treats all data as though they were drawn from an Gaussian distribution over the possible functions the light curve could take. We implement this using a python package (73), interpolating at a daily cadence using a Matern-3/2 kernel. We then fit the resulting spectral energy distributions at each epoch of the interpolated light curves with a simple black body function. From this constructed bolometric curve, we estimate the peak luminosity to be $4.2 \pm 0.1 \times 10^{43} \text{ erg s}^{-1}$.

In the luminosity-rise time parameter space shown in Figure 3, AT2020neh occupies a unique position, being fast and also brighter than other shorter-lived TDEs. These two properties are comparable to those observed within FBOT events, known for their short-lived optical lifetimes and often bright peak luminosities. FBOTs are also frequently characterised by their

rapidly cooling photospheres (16, 17, 74), with some events cooling by $> 10,000\text{K}$ in the early stages of their declines (16). The UV-optical light curve of AT 2020neh exhibits significant cooling during the first 30 days from peak, with a black body temperature decrease of approximately 9000 K (Extended Data Figure 3). Although a cooling photosphere is not associated with many optically discovered TDEs, the majority of which exhibit a constant or even increasing temperature after peak (69), apparent cooling of the photosphere has been observed a few events, e.g. iPTF16fnl, AT 2019qiz and several TDEs discovered by ZTF (3, 12, 69, 75). The rate of cooling of AT 2020neh is comparable to these events, which typically display a $\Delta T/\Delta t \gtrsim 5000\text{ K} / 20\text{ days}$ (12, 69, 75), but much slower than the cooling observed in FBOTs like AT 2018cow (Extended Data Figure 3). As the exact source of the optical emission in TDEs is unknown, alongside the physical mechanisms which produce it, it is not clear why some TDEs exhibit this cooling behaviour, although it has been suggested that it may be linked to optically thick outflows, where cooling of the photosphere occurs when the outflow reaches a characteristic photon trapping radius from which photons are able to escape (12). However it is currently not clear whether this scenario is applicable to the majority of cooling cases in TDEs.

From only photometric information, it is difficult to discern FBOTs from TDEs from lower mass BHs. The physical origins of FBOTs are disputed, but some have had a TDE origin suggested for their production (e.g. 15, 68). We use the transient rise times to estimate approximate black hole masses for TDEs (shown along the upper axis of Figure 3), assuming a standard encounter with a solar mass star. Using this metric, we can see that ‘faster rising’ AT 2020neh-like events probe the regions of super-Eddington accretion for lower ($M_{BH} < 10^{5.5} M_{\odot}$) mass BHs.

Astrometric Location The location of AT 2020neh within its host galaxy can also be used to help discriminate between theories for its origin. AT 2020neh is located in SDSSJ152120.07+140410.5, a galaxy at a spectroscopic redshift of $z = 0.062024$. We use pre-explosion template PS1/3 π images to determine the centroid of the host galaxy, which we find to be RA=15^h21^m20.087^s, Dec=+14°04′10.665″ (with a centroid uncertainty of 0.09″). To determine the location of AT 2020neh in the pre-explosion reference images we performed astrometry using both YSE PS1 images of the transient close to maximum light in the g,r and i bands, and with acquisition imaging from Gemini from 11 Jul 2020. In all cases we use routine IRAF tasks to determine the coordinates of cross-matched point sources in both transient and reference images, then map and transform these coordinates to find the transient location in the reference image. We find a mean location of RA=15^h21^m20.094^h Dec=+14°04′10.723″ ($\pm 0.12''$). We cross check this location using the late time ultraviolet imaging from HST. We find the HST location to be RA=15^h21^m20.089^h Dec=+14°04′10.546″ ($\pm 0.3''$), consistent with our ground-based measurements. The larger uncertainty in the HST measurement is due to a lack of corresponding point sources in the ultraviolet image, so we use our ground based estimates as our final location. The location corresponds to a nuclear separation of 0.13″(or a physical separation of 0.16 ± 0.15 kpc), consistent with the transient being of nuclear origin (Figure 1). This separation is also consistent with the range of offsets for radio detected black holes in dwarf galaxies (38). The nuclear location of the transient is inconsistent with the distribution of locations and offsets observed within the FBOT population from their apparent host galaxies (17, 76), which are not typically associated with the centres of their hosts.

Host Galaxy Properties

Host-Galaxy Spectral Properties We take optical spectroscopy of the host of AT2020neh from SDSS. We measure the emission lines present using standard routines within IRAF and plot the resulting emission line ratios on a BPT diagram (77), shown in Extended Data Figure 4. The BPT diagram uses emission line ratios to create theoretical regions used to identify the main excitation mechanisms which produce them (78); namely star formation, AGN shocks or a composite of the two. The host galaxy of AT2020neh lies within the star-forming region, close to the composite border.

Pre-explosion Variability Given the proximity of the host galaxy to the composite region of the BPT diagram, we consider the possibility that AT2020neh may have occurred in an environment with a pre-existing accretion disk (and therefore may be the result of AGN activity). From our early monitoring of the field with YSE (coverage from 24 Mar 2020 to 17 Jun 2020 in g, r, i down to $m \sim 21.5$), we find no significant variability outside of a 1σ range from the mean of the forced photometry at the transient location over this 3 month period. We check for long-term variability using pre-explosion photometry available from ZTF (coverage from 27 Mar 2018 to 20 Jun 2020 in g, r) and from the Catalina Real Time Survey (CRTS) which monitored the host galaxy from 6 Apr 2005 to 16 Jun 2013 in a clear filter. We then use the fitting software `qso_fit` (79) to fit the pre-explosion photometry data sets to determine whether the light curves exhibit significant variability characteristic of an AGN. `qso_fit` generates a model light curve by modeling each point given the previous detections and a model co-variance matrix for AGN variability, then assesses how well the best-fit damped random walk model describes the data. Variable AGN typically have

a significance of variability, σ_{var} , greater than 2 (42). We find the significance that the host galaxy of AT 2020neh is variable to be low ($\sigma_{var}=0.06$ and 1.19 from ZTF and CRTS respectively) and the significance that the source is an AGN to also be low ($\sigma_{QSO}=2.02$ and 1.53 from ZTF and CRTS, where the typical significance for an AGN to be would is $\sigma_{QSO} > 2$, (42)). Therefore it is unlikely that AT 2020neh harbours an active AGN or that the transient is due to AGN activity, in agreement with the host-galaxy location on the BPT diagram.

Host Galaxy Spectral Energy Distribution To perform Spectral Energy Distribution (SED) fitting of the host galaxy of AT 2020neh, we use archival photometry from the PS1 3π catalog in the g, r, i, z and y filters, alongside J, H, K measurements from the 2 Micron All Sky Survey (2MASS, 80), W1-3 bands from the Wide-field Infrared Survey Explorer (WISE; 81) and NUV and FUV photometry from the Galaxy Evolution Explorer (GALEX; 82). To account for the systematic uncertainties in the photometry and in the physical models being fit to the emission, we apply a 10% error floor to all photometry, with a 30% error floor to the WISE W3 photometry, to account for variations in silicate absorption features around $10\mu\text{m}$ (83).

We then derive the physical properties of the host galaxy by fitting the collated photometry using the stellar population synthesis models in PROSPECTOR (83), considering wide priors on stellar mass, metallicity and star-formation history. We create a model which includes the effects of stellar and nebular emission, metallicity, dust reprocessing, and an exponentially declining star-formation history. We sample the posterior using the Bayesian nested sampling code DYNESTY (84). The galaxy SED and prospector fitting results are shown in Extended Data Figure 4. The model encapsulates the shape of the host-galaxy SED well. We find a stellar mass $\log(M_{\star}/M_{\odot}) =$

$9.57^{+0.02}_{-0.01}$ and a low star-formation rate of $SFR = 0.33^{+0.06}_{-0.06} M_{\odot} \text{yr}^{-1}$ and a metallicity of $\log(Z/Z_{\odot}) = 0.13^{+0.19}_{-0.17}$. To account for the uncertainties introduced from assumptions made within the SED fitting on the galaxy star formation history and dust attenuation laws, we inflate our uncertainties in the stellar mass estimate to $\log(\Delta M_{\star}/M_{\odot}) = 0.19$, in accordance with the average uncertainty in stellar masses fitted with an exponentially declining star formation history in PROSPECTOR (85).

Using the derived stellar mass, we can estimate the mass of the central black hole using a known scaling relation for low-mass galaxies (22);

$$\log\left(\frac{M_{BH}}{M_{\odot}}\right) = \alpha + \beta \log\left(\frac{M_{\star}}{10^{11} M_{\odot}}\right) \quad (1)$$

where $\alpha = 7.45 \pm 0.08$ and $\beta = 1.05 \pm 0.11$. Using this scaling relation we estimate the mass of the black hole to be $\log M_{BH}/M_{\odot} = 5.95^{+0.20}_{-0.20}$

Host Galaxy Spectral Modelling We use the late time (+74d rest-frame) spectrum of AT 2020neh taken with the DEIMOS spectrograph on Keck to measure the line-of-sight stellar velocity dispersion of the host galaxy. We use regions of the spectrum which are located away from the TDE line emission at this epoch to measure the stellar velocity dispersion to minimise contamination. The resolution of the DEIMOS spectrum ($R \approx 6000$) is finer than that of the archival SDSS spectrum of the host galaxy, and given that the stellar velocity of dwarf galaxies is expected to be low (42), we chose to use this higher-resolution spectrum rather than the transient free SDSS spectrum to estimate the velocity dispersion. We use the Penalized Pixel Fitting software (pPXF; 86, 87) to determine the stellar kinematics of the galaxy. pPXF uses the spectral features in a galaxy spectrum

alongside a set of stellar templates to determine the stellar line-of-sight velocity distribution. We use the high-resolution spectral templates from the X-shooter Spectral Library (88), which contains spectra of 628 stars in the UVB arm and 718 stars in the VIS arm at a spectral resolution of $R \approx 10,000$. We convolve these spectra with a Gaussian of $\sigma = 2.39\text{\AA}$ to match them to the lower resolution of our DEIMOS spectrum ($R \approx 6,000$). We focus on two wavelength regions covering the Mg Ib triplet at $5160 - 5190\text{\AA}$ and the Na-D doublet at $5890, 5895\text{\AA}$. We fit each of these regions separately, using the X-shooter UVB and VIS templates. We fit regions between $4700 - 5550\text{\AA}$ and $5400 - 6200\text{\AA}$ (both rest frame), masking the TDE spectrum outside of these windows, and fitting only for the first two moments of the line-of-sight velocity distribution (V and σ).

To estimate the uncertainty on the velocity dispersion fitted we use a Monte Carlo bootstrap method (89), where we resample the 1-D spectrum based on the error spectrum, recalculate the velocity dispersion for 1000 noise realizations. From the resulting distribution of velocities we take the mean to be the final value, and the uncertainty to be the square root of the variance of the distribution. The best fitting stellar templates are presented in Extended Data Figure 5. We find the independently measured velocity dispersions to be $\sigma = 40 \pm 6 \text{ km s}^{-1}$ and $\sigma = 38 \pm 13 \text{ km s}^{-1}$ fitting the UVB and VIS templates respectively. Given the low signal-to-noise of the host-galaxy stellar features in the VIS arm, we adopt our UVB measurement for our velocity dispersion estimate of the host galaxy.

From the velocity dispersion, we estimate the central black hole mass using using a $M_{BH} - \sigma$ relation (30);

$$M_{BH} = 1.4 \times 10^8 M_{\odot} \left(\frac{\sigma}{200 \text{ km s}^{-1}} \right)^{4.72}. \quad (2)$$

From our measured velocity dispersion, we estimate the mass of the black hole to be $\log M_{BH}/M_{\odot} = 4.8^{+0.4}_{-0.2}$.

Stellar Surface Mass Density We examine the stellar surface mass density, ΣM_* of the host galaxy, which when considered alongside the velocity dispersion of the host galaxy, has been shown to be higher for TDE host galaxies compared to field galaxies in the local Universe (20), increasing the likelihood of a TDE occurring. The stellar mass surface density of the host galaxy is characterised as:

$$\Sigma M_* = \frac{M_*/M_{\odot}}{r_{50}^2/\text{kpc}^2} \quad (3)$$

where M_* is our derived stellar mass and r_{50} is the half-light radius enclosing 50% of the host-galaxy flux. Using SOURCE EXTRACTOR we determine the 50% flux radius using the pre-explosion template PS1/3 π image of the host galaxy in the SDSS r-band, setting a detection limit of 3σ above the background sky. We measure an r_{50} of 1.75 ± 0.07 kpc, which gives a surface mass density of $\log \Sigma M_* = 9.08$.

Comparison to TDE Host Galaxies The host galaxy of AT2020neh has some similarities to the existing population of TDE hosts, but also has properties which make it unique.

The stellar mass of this galaxy places it towards the lower end of the TDE host-galaxy mass function, joining a small but growing number of optical TDEs in dwarf host galaxies (69). Though this and other measured properties of the host galaxy of AT 2020neh (star formation rate and BPT

location) are not significant outliers amongst other optical TDE host galaxies, (21, also see Extended Data Figure 4.), the color of the host galaxy is very blue ($u - r = 1.7$), suggestive of on-going star formation. This is different to previous TDEs, whose higher mass host galaxies typically have low star formation rates or are post-starburst systems (21, 90), and does increase the possibility for contamination from SNe II. However, the host galaxy also possesses a relatively high Sérsic index ($n = 3.2$) and stellar surface mass density compared to SDSS field galaxies. High Sérsic indices have been observed in other TDE hosts (20, 90). These over-densities of stars close to the galaxy nuclei are thought to enhance the TDE rate as they increasing the number of stars capable of being disrupted (21). It may be that this is necessary for the production of a TDE within low mass starforming host galaxies.

Light Curve Modelling

The rate of fallback of the stellar debris from the disrupted star onto the central black hole and the peak timescale of the resultant TDE emission are sensitive to the mass of the disrupting black hole ((27, 29, 91)). Assuming the emission from the TDE is ‘prompt’ (i.e. follows the fallback rate of material; 27), the light curve can be in principle used to measure the mass of the disrupting black hole.

We fit the multi-band light curve of AT2020neh using the MOSFiT light curve fitting code (Modular Open Source Fitter for Transients; 92). The MOSFiT TDE model uses FLASH hydrodynamic simulations of TDEs (93) to calculate the fallback rate of debris for a given TDE set-up (i.e. black hole mass, stellar mass and impact parameter). Assuming a black body SED, which

has shown to be an excellent approximation to TDE UV and optical emission (6), this is then converted into a bolometric luminosity and parsed through reprocessing and viscosity transformation functions to generate multi-band light curves. Finally, MOSFiT uses a Markov Chain Monte Carlo (MCMC) to fit the model light curves to the data. Full details of this model are presented within (29). When fitting, we do not implement the default Eddington luminosity limit in the TDE model or limit the photospheric size of the transient. Most notably we are able to place firm constraints on the time of first fallback due to our early YSE photometric limits and detection.

We present our light curve fits from all MCMC walkers in Extended Data Figure 6. We extract the posterior distributions for the key model parameters from MOSFiT, and find AT 2020neh is best described by models invoking a star of mass $M_{\star} = 1.3^{+4.9}_{-1.0} M_{\odot}$, and impact parameter of $\beta = 1.5^{+0.4}_{-0.9}$ (consistent with a near full disruption for the best-fit stellar mass) and a black hole with $\log M_{BH}/M_{\odot} = 5.5^{+0.4}_{-0.3}$. The black hole mass is consistent with our previous estimates from the host-galaxy properties. We note that the mass of the star is somewhat degenerate with the efficiency parameter in this model (29). To account for this, a systematic uncertainties of $\sigma_{M_{\star}} = 0.66$ and $\sigma_{\epsilon} = 0.68$ are included in our error budget (29). The strong nitrogen abundance observed in the early spectrum of AT 2020neh without accompanying hydrogen could suggest a more evolved or stripped progenitor star, although high nitrogen abundances have been seen in other TDEs whose inferred stellar masses are consistent with the MOSFiT stellar mass for 2020neh (94).

The MOSFiT BH mass is in good agreement with the BH masses inferred from two host galaxy measurements, increasing confidence that AT 2020neh is produced by an IMBH candidate. However, there is still considerable debate as to the physical origin of the early optical and UV

emission from TDEs, and it is uncertain how well they can be used as an independent way of measuring BH mass. This needs to be carefully considered when using TDE inferred BH masses to constrain BH-galaxy scaling relationships.

Though the BH masses inferred from light curve modelling have large inherent uncertainties due to the assumptions made within the model (MOSFiT BH masses have a 0.2 dex systematic error), they are not always in agreement with masses derived via other methods (29). For instance, some studies have found no correlation between TDE rise time and host-galaxy mass (6, 69), which would be expected if the rise time follows the fallback timescale of material onto the BH. In particular, optical TDEs from other low mass host galaxies have been found to have generally higher MOSFiT BH masses than those inferred from the host galaxy mass (69). However, alternative studies have found a moderate scaling between MOSFiT BH masses and the mass of the host galaxy bulge (95, 96). The discrepancy in BH mass estimates from TDE rise times may be due to the physical origin for the early optical/UV emission. If, rather than following the fallback of material, the rise time of a TDE were actually tracing the radiative diffusion timescale for photons to escape the shock-heated stellar debris, or if the photons were trapped by outflowing material, this would naturally lengthen the time taken to rise to peak (6, 14).

It is currently unclear which, if any, of the proposed physical mechanisms is prevalent in the production of early optical TDE emission. Though there is no firm consensus as to their utility for measuring BH masses, there is tentative evidence to suggest that they could be harnessed for this purpose, following a more sound understanding of their emission. Larger samples of well-observed TDEs across a range of galaxy masses are required to test this.

Rate estimations and predictions

To estimate the local rate of TDEs with timescales and luminosities comparable to AT 2020neh we assume the following; over 24 months of YSE operations we have observed only one AT 2020neh-like event, monitoring fields for approximately 6 months each. This equates to one event per year within the YSE observational volume. At the time of writing, the observational footprint of YSE is 750 deg^2 of the northern hemisphere. We perform a volumetric correction to account for the maximum volume over which AT 2020neh could have been detected within the YSE survey (V_{max}). Under the current YSE observational strategy (2), we assume that a fast TDE may rise by 0.2 magnitudes before initial detection. This gives us a maximum redshift of $z = 0.27$, which produces a volume of $\sim 23 \times 10^6 \text{ Mpc}^3$. This provides an approximate observational rate of fast TDEs of $\lesssim 2 \times 10^{-8} \text{ Mpc}^{-3} \text{ yr}^{-1}$ at $z = 0.27$.

For comparisons with the normal-TDE rate, we take the average per-galaxy TDE rate measurement of (25) for galaxies in the mass range $9.5 < \log \frac{M_*}{M_\odot} < 10.5$, and integrate this over the number of galaxies within our V_{max} volume using the redshift dependant galaxy-mass functions of (97), producing an average rate of $\sim 10^{-6.3} \text{ Mpc}^{-3} \text{ yr}^{-1}$ at $z = 0.27$. We emphasize that this is a conservative estimate as both stochastic effects from measuring rates based on a single object and small observing gaps that lower the YSE detection efficiency for fast transients could lower the estimated rate

The discovery and functionality of future fast TDE events will heavily depend upon the observing strategies of the surveys they are discovered in. Provided a survey has sufficient depth, fu-

ture fast TDEs may be detected at any phase of their evolution. However, the utility of AT 2020neh as a probe of the quiescent BH population lies in its early detection to constrain the rise time for BH mass estimates. Hence the cadence of the discovery survey will have the strongest impact on the usefulness of future fast TDEs. High-cadenced, deep surveys such as YSE will reliably identify fast TDEs in their infancy. With the planned doubling of the YSE footprint during 2022, based on our earlier rate estimate, we predict that YSE will identify an additional 5-6 events over the remaining 3 years of survey operations.

Data Availability Statement

All photometric data are available in Extended Data Table 3 and the spectra of AT 2020neh will be made publically available to the community via WISEREP (98, <http://wiserep.org>).

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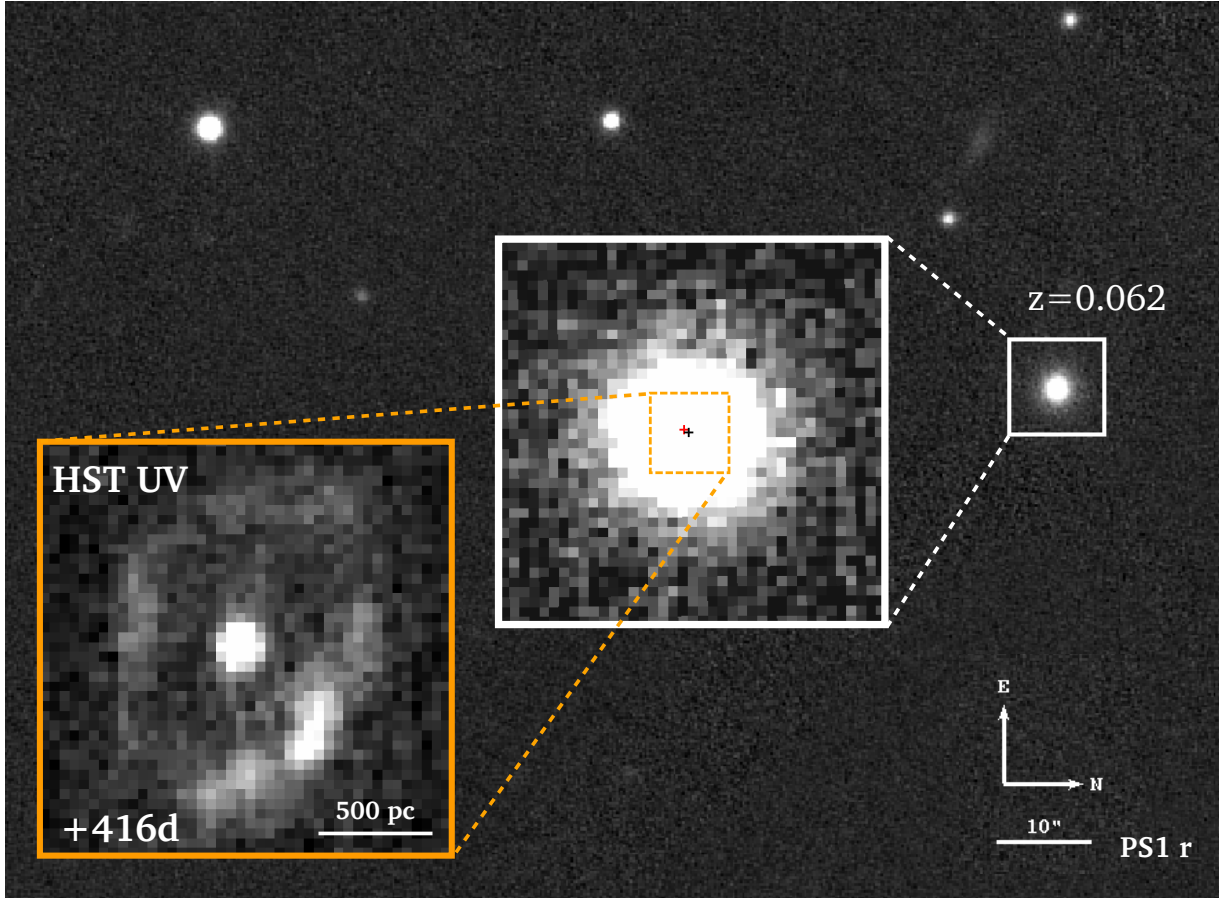


Figure 1 | The nuclear transient AT 2020neh. The wider image shows the environment of AT 2020neh in optical PS1 *r*-band imaging. The dwarf host galaxy of the transient is highlighted. The first inset shows the apparent location of AT 2020neh within its host galaxy in the optical. The host centroid is marked with a black cross whilst the location of AT 2020neh is marked with a red cross (shown with 1σ astrometric uncertainties). The location of the transient is coincident with the host nucleus. A second inset (orange boarder) shows deep ultraviolet imaging from the Hubble Space Telescope of AT 2020neh at +416d. The transient is still clearly detected at the centre of the host, surrounded by a ring of star formation approximately 600pc from the nucleus.

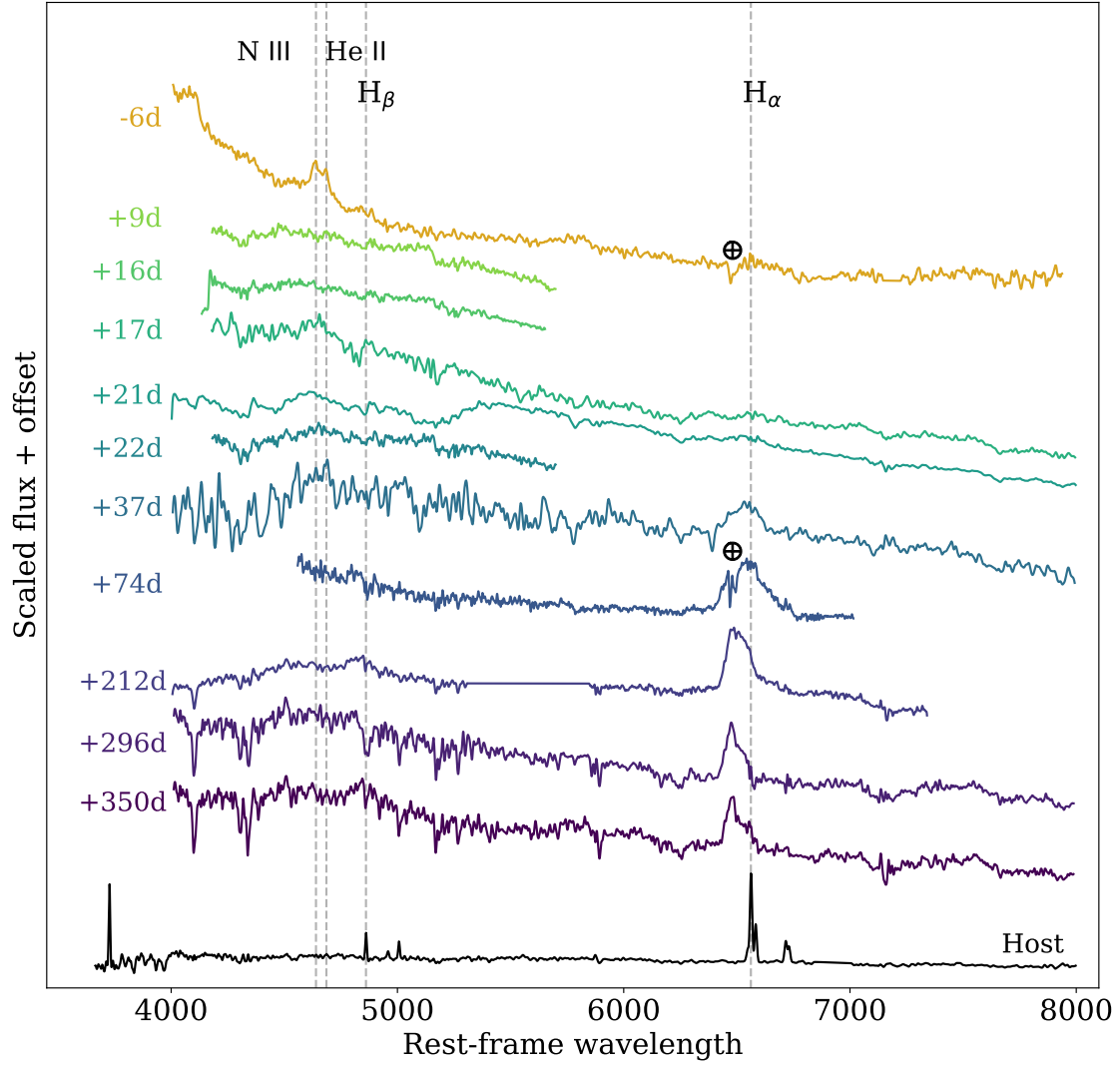


Figure 2 | The spectroscopic evolution of AT 2020neh. Common TDE emission features (H, He, N) are marked. The strong He II and N III emission seen pre-maximum light disappears after the peak, with Balmer emission appearing at much later epochs, becoming increasingly asymmetric and blue-shifted as the TDE evolves. Spectra have been offset for clarity with rest-frame phases indicated. Crossed circles mark telluric features still present within the spectra. The instruments used to obtain this data are listed in Extended Data Table 1.

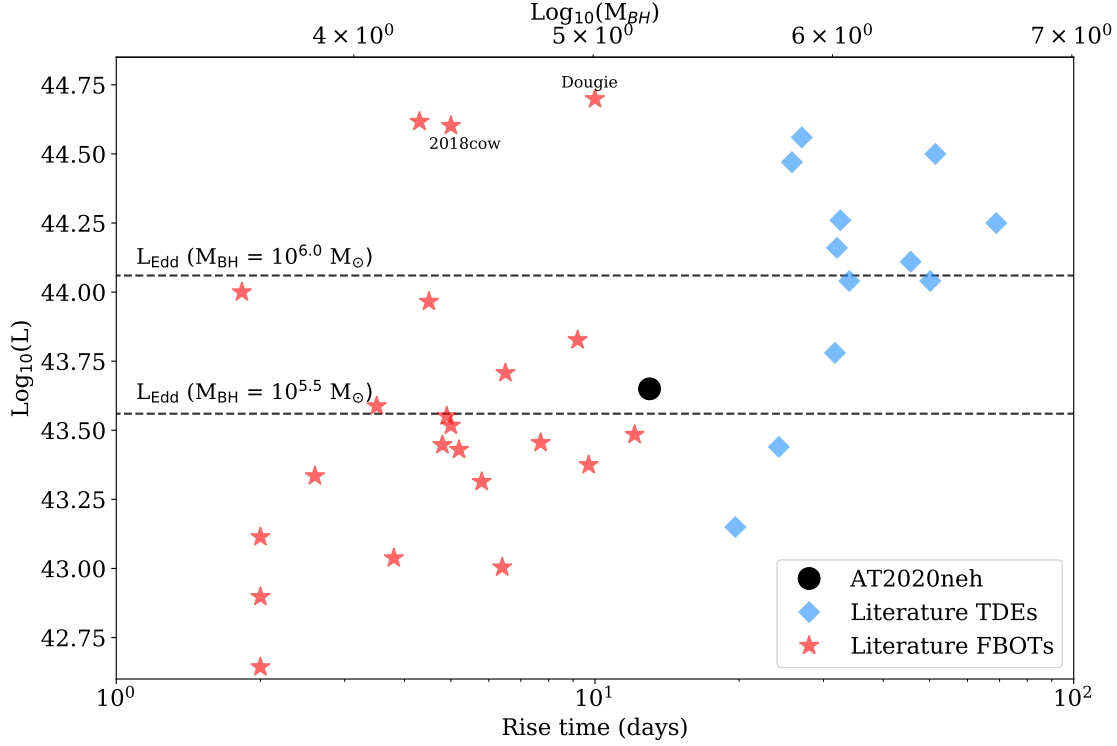


Figure 3 | The rise-luminosity distribution of TDEs and FBOTs . The measured rise times of TDEs (blue circles) from the literature with pre-peak coverage as a function of their peak luminosities. AT 2020neh occupies a unique position within this parameter space, being fast for a TDE and brighter than other short lived TDEs, lying between TDEs and the FBOT population, marked by red stars (17). More energetic FBOT events such as ‘Dougie’ (15) and AT2018cow (16) are marked. Using the transient rise time to estimate the black hole mass for the TDE events (upper axis), we can see that ‘faster rising’ AT 2020neh like events probe the regions of super-Eddington accretion for lower ($M_{BH} < 10^{5.5} M_{\odot}$) mass BHs (dashed lines).

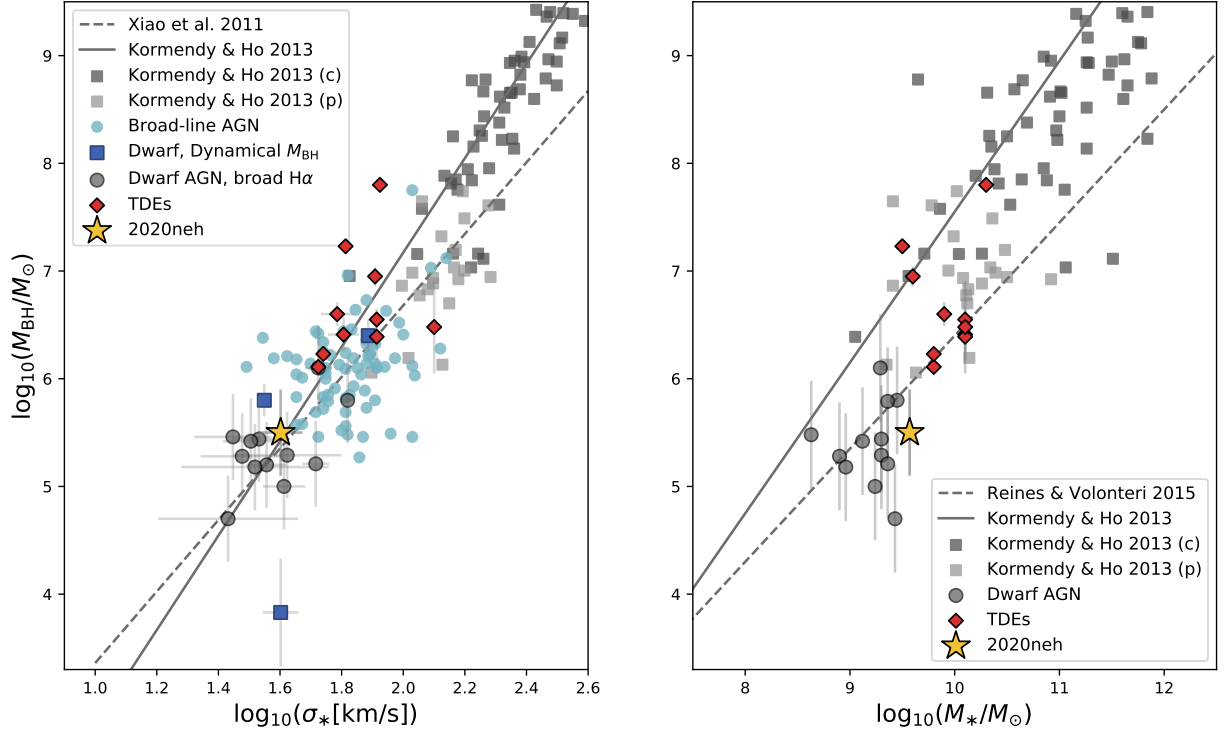
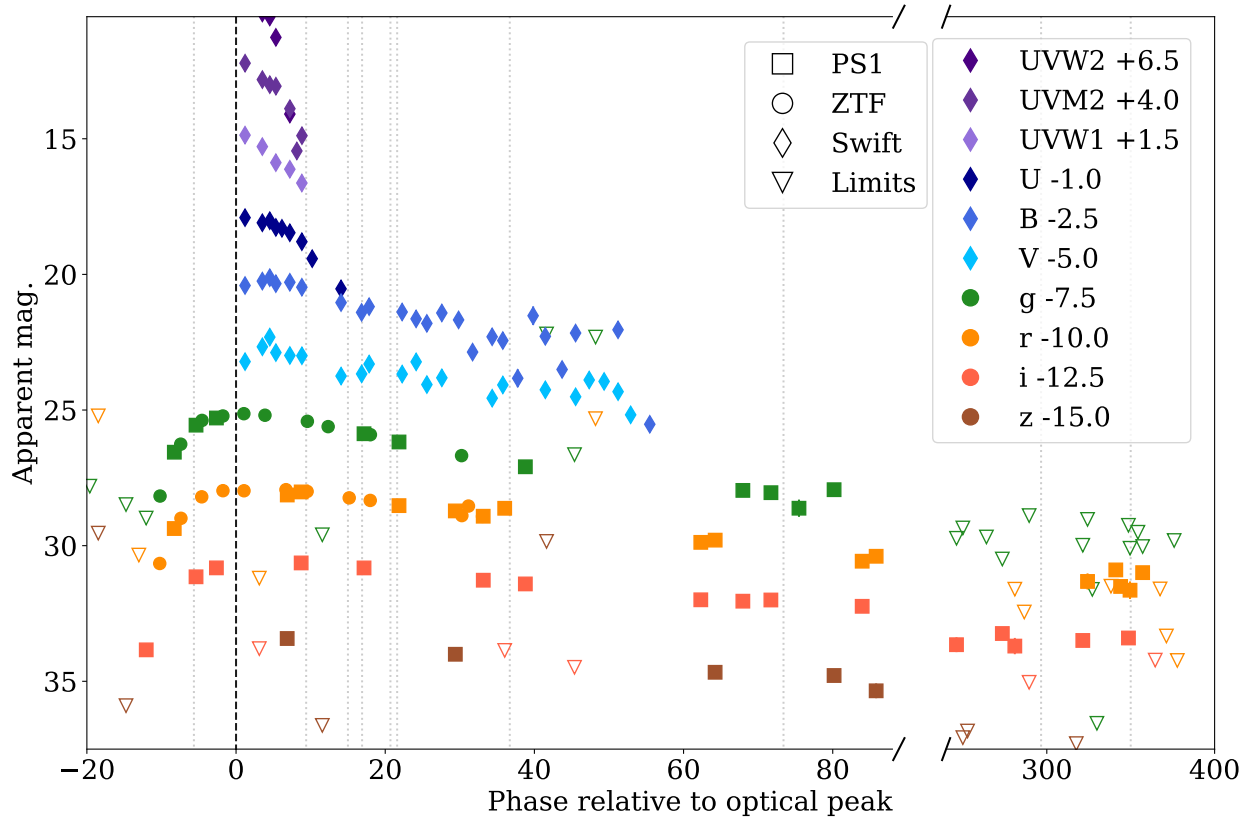
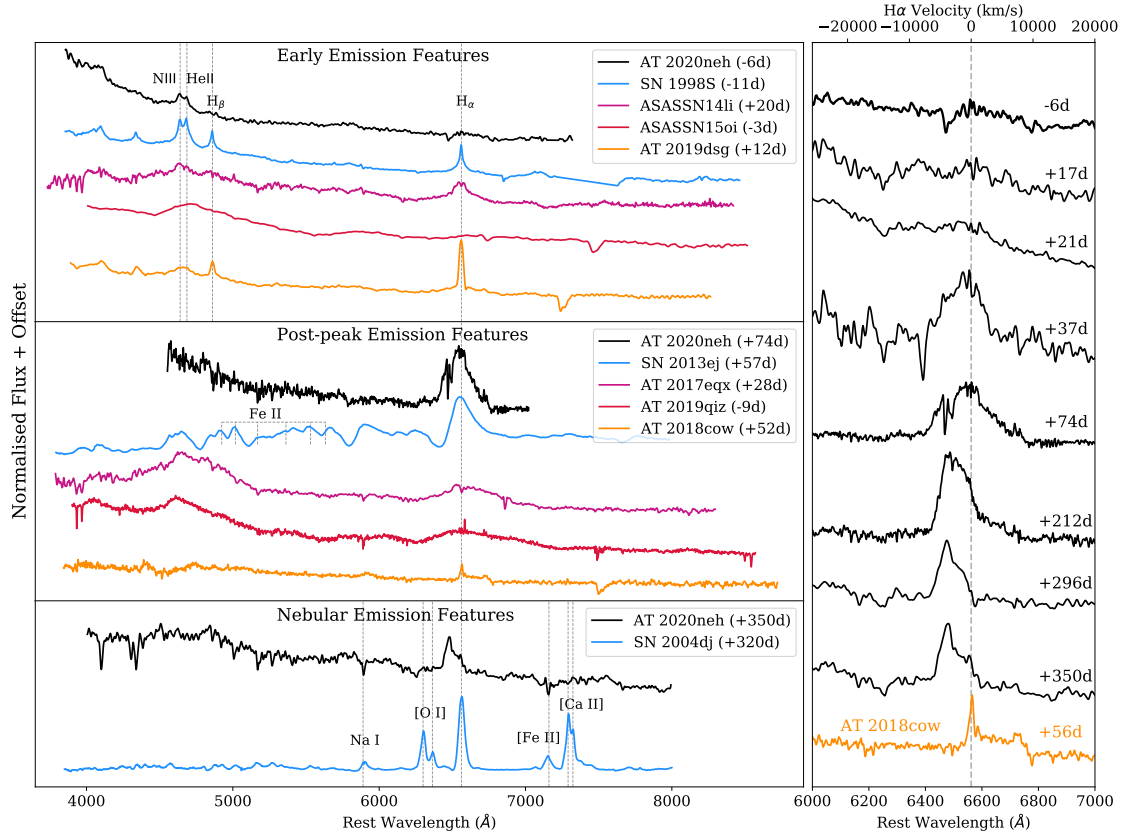


Figure 4 | Black hole scaling relations including dwarf galaxies . BH mass versus stellar velocity dispersion for samples of local galaxies (*left*), alongside BH mass versus galaxy stellar mass (*right*). Compilation samples of galaxies from (46) are shown in grey squares, and broad line AGN from (47) are shown in light blue, alongside fits to the scaling relations. Dwarf AGN from (36, 42) are shown as dark grey circles. TDEs with BH mass estimates from (29) are shown in red, and AT2020neh is shown as a yellow star on both plots. The majority of galaxies with BH mass estimates in the low stellar mass/low velocity dispersion regime are those derived from the velocity of gas in the broad line region using the H-alpha line, which has large uncertainties. AT2020neh is one of a few BHs with an independent mass estimate in this region.

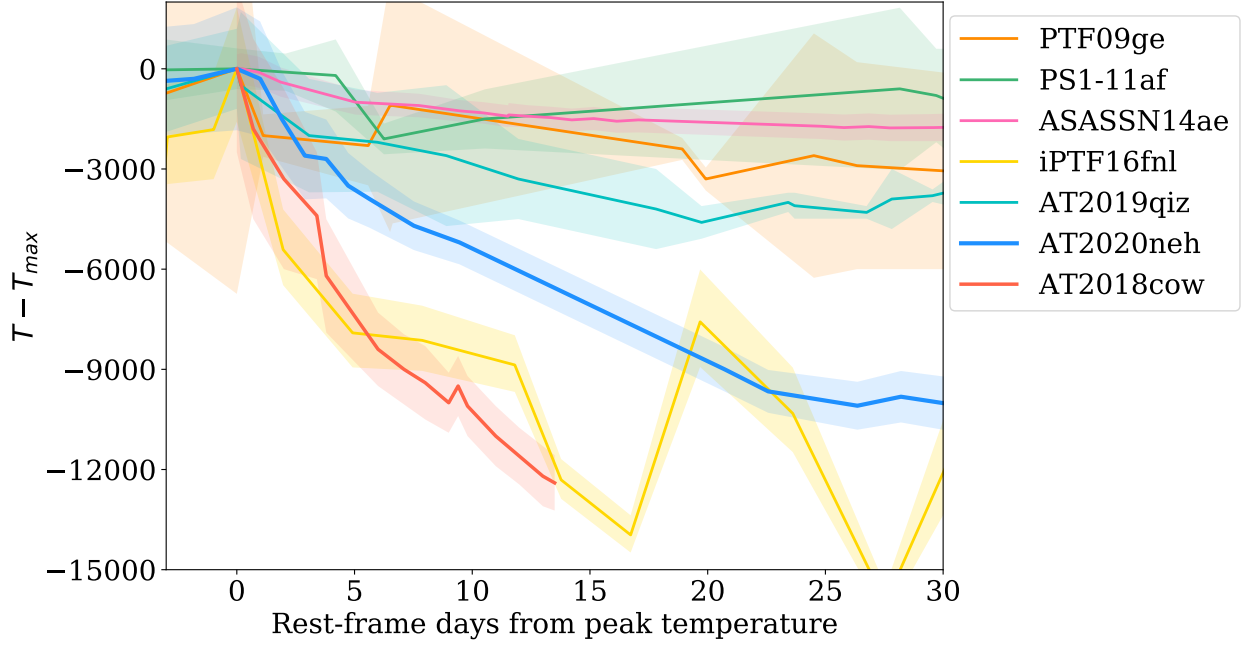


Extended Data Figure 1 | Light curve of AT 2020neh. The UV-optical light curve of AT 2020neh throughout its observable lifetime. Grey dashed lines mark spectroscopic epochs, the dashed black line marks the peak of optical emission. Limits represent 3σ upper limits to the flux for each telescope during periods of non-detection. There is an apparent gap in optical data between 40-60 days due to poor weather. AT 2020neh is first detected within YSE (PS1) imaging in the *i*-band, confirmed by with a *g*-band detection from ZTF <24 hours later. Pre-explosion monitoring allows for strong constraints to be placed upon the explosion epoch of the transient.

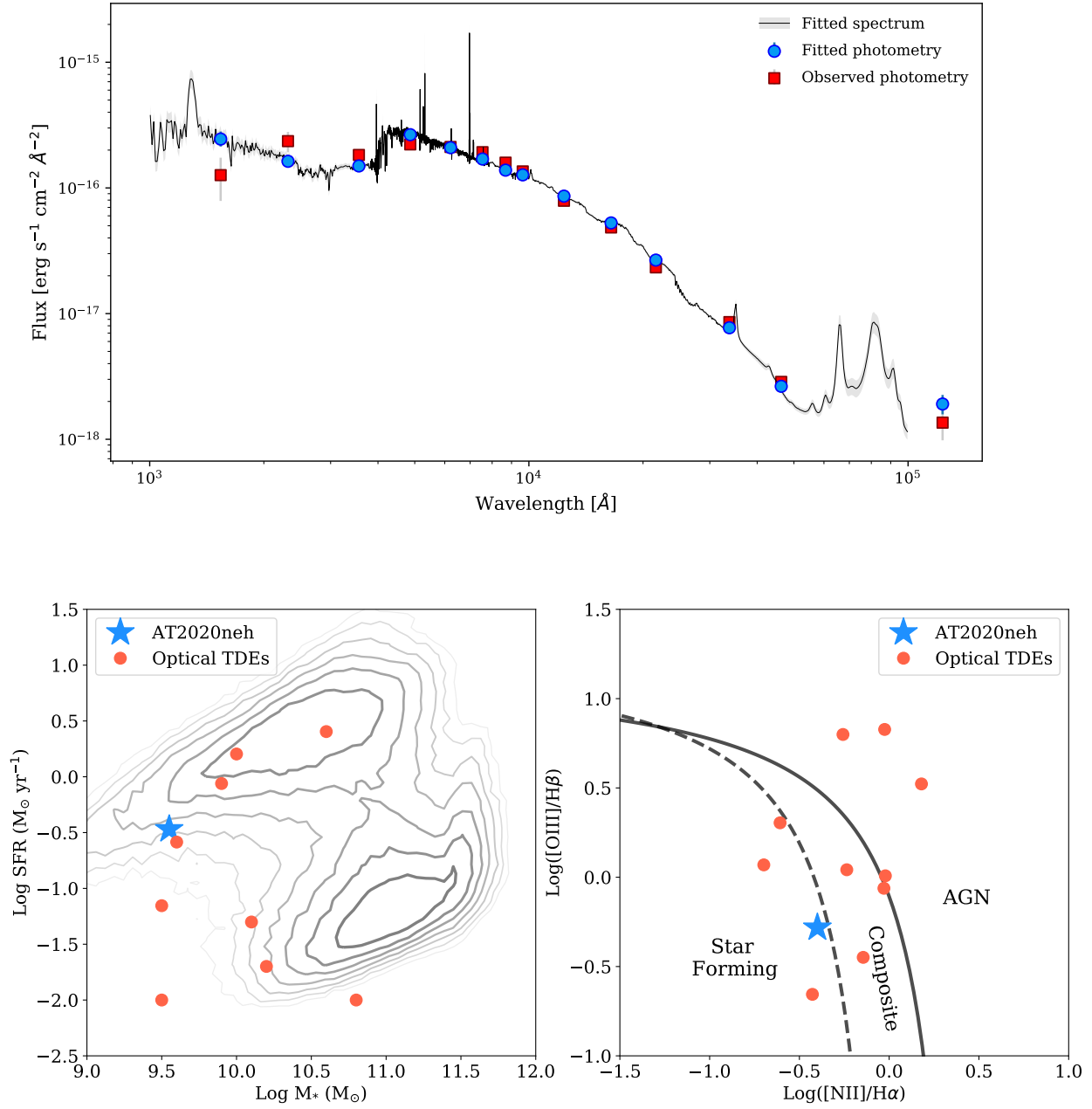


Extended Data Figure 2 | Spectroscopic comparison with other transients. *Top:* The early time spectrum of AT 2020neh alongside other TDEs which show Bowen fluorescence and an example of an alternative to this interpretation (CCSN flash-ionisation, as exemplified in SN 1998S). *Middle:* Comparison of the post-maximum features in AT 2020neh with other TDEs, a CCSN and the FBOT AT 2018cow. AT 2020neh presents a H α profile in emission, lacking the typical P-Cygni profile of a SN II but much broader than the FBOT. The rest of the spectrum is featureless, lacking absorption features from iron-group elements which would be expected of a CCSN during the photospheric phase. *Bottom:* The ‘nebulary’ phase spectrum of AT 2020neh alongside a nebular phase CCSN. Expected emission features from SN during this phase are marked. *Right:* The evolution of the

H α profile of AT 2020neh. This feature appears late in the post-peak evolution, and retains a strongly blue-shifted profile, unseen in normal SNe. The narrow profile of AT 2018cow is shown for comparison.

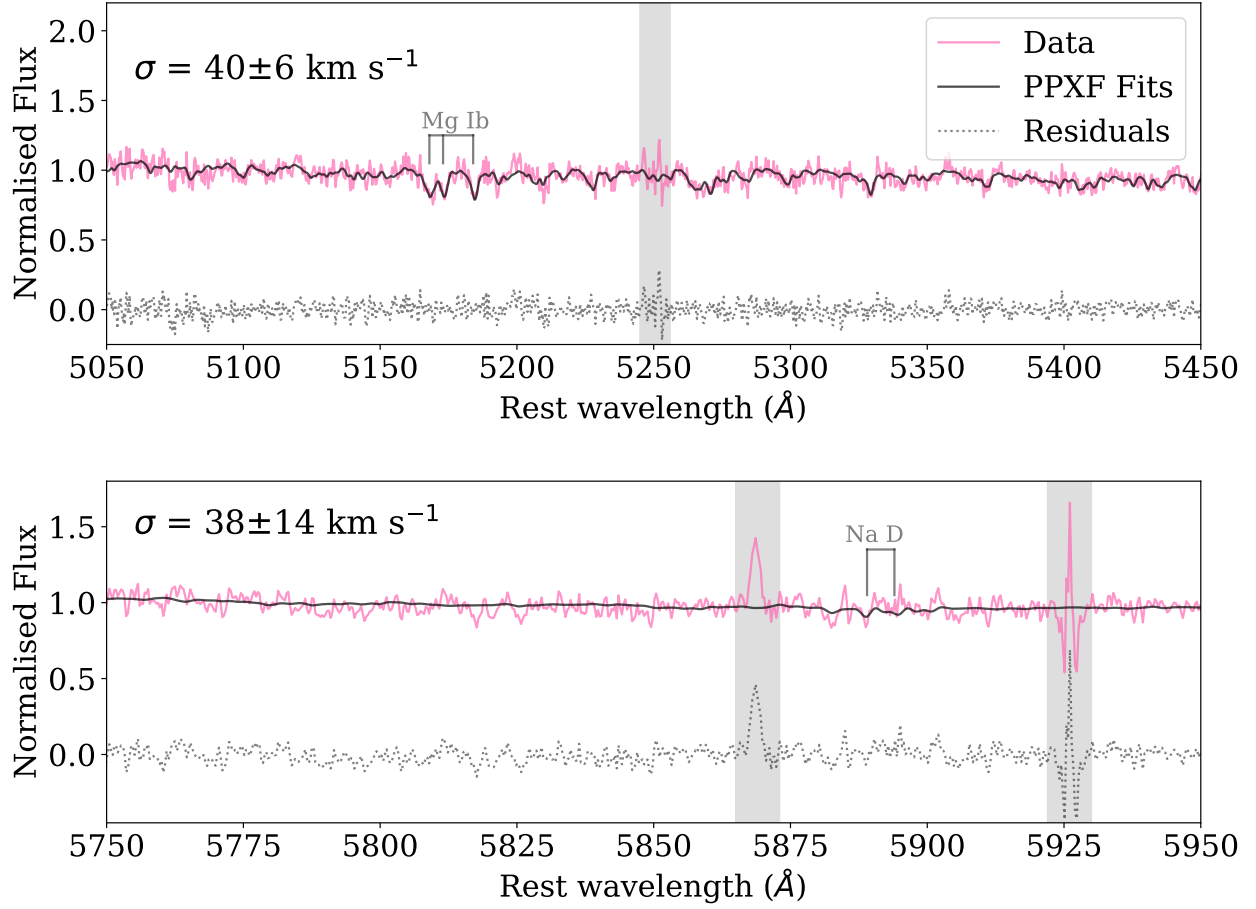


Extended Data Figure 3 | Cooling rates of transients The early time cooling AT 2020neh compared to that exhibited in the optically selected TDEs, including AT2019qiz and iPTF16fnl, alongside the FBOT AT 2018cow. AT 2020neh does exhibit significant cooling of approximately 9000k during the first 30 days from peak. This rate of cooling is comparable to that observed in iPTF16fnl and AT 2019qiz, which are both believed to be produced by relatively low mass SMBHs ($M_{BH} \sim 10^6 M_{\odot}$; (3, 12)). This rate of cooling is much slower than that exhibited by AT 2018cow, which cools by nearly 10,000K in the first 10 days from peak (16).

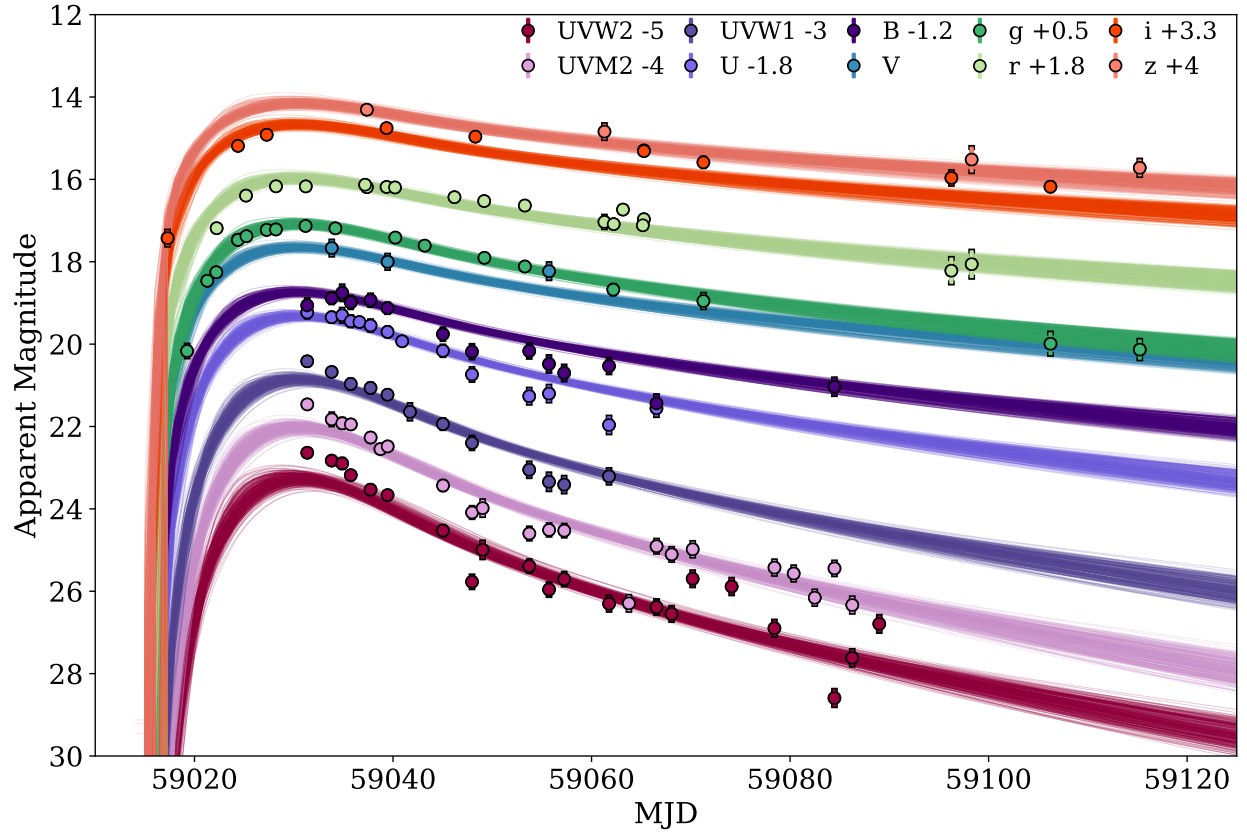


Extended Data Figure 4 | Properties of the host of AT 2020neh *Top*: The PROSPECTOR SED fit to the host galaxy photometry *Bottom left*: Star formation rates vs. stellar masses for field galaxies (shown here is the SDSS spectroscopic sample as grey contours). The hosts of optical TDEs are

shown in red (taken from 21). AT 2020neh sits comfortably within the parameter space occupied by other TDEs. *Bottom right:* A BPT diagram showing the regions where emission line ratios are indicative of ionisation from either an AGN, star formation or a composite of the two (78). The location of AT 2020neh is shown, alongside other optical TDE hosts with host SDSS spectra (21). The position of AT 2020neh inside of the star forming region of the diagram confirms the lack of an AGN component within the host.



Extended Data Figure 5 | Fitting the velocity dispersion of the host The late-time DEIMOS spectrum of AT 2020neh used to fit the stellar absorption features is shown, highlighting the regions around the Mg Ib triplet (top) and the Na D doublet (bottom). These two regions are fit independently. The best-fitting pPXF model is shown alongside each spectrum. We perform Monte-Carlo bootstrap fitting of the data to determine the uncertainties on the velocity dispersion.



Extended Data Figure 6 | MOSFtT modelling of the light curve of AT 2020neh Photometry of AT 2020neh in UV-optical bands (offset for clarity) alongside all possible TDE light curves each constructed from the posterior parameter distribution.

Extended Data Table 1 | H α Emission Properties

Phase	Flux ($\times 10^{-15}$ erg s $^{-1}$)	$\lambda_{observed}$ (\AA)	Velocity offset (km s $^{-1}$)	EW (\AA)
+37d	4.78 ± 0.04	6528 ± 3	-1526 ± 137	80 ± 9
+74d	16.10 ± 0.08	6525 ± 10	-1709 ± 457	105 ± 12
+212d	18.65 ± 0.02	6480 ± 1.0	-3767 ± 46	129 ± 8
+296d	3.02 ± 0.03	6475.1 ± 1.3	-3990 ± 65	80 ± 3
+350d	3.14 ± 0.04	6475.2 ± 1.7	-3990 ± 79	82 ± 4

Extended Data Table 2 | Spectroscopic Followup Observations.

Date (UT)	Phase	Telescope	Instrument	Grating	λ Range (Å)
25/06/2020	-6 d	NOT	ALFOSC	Gr 4	4000 - 9000
11/07/2020	+9 d	Gemini	GMOS-N	B1200	4400 - 6000
17/07/2020	+ 15 d	Gemini	GMOS-N	B1200	4400 - 6000
19/07/2020	+17 d	Shane-3m	KAST	B452/3306	3300 - 6200
				R300/7500	3300 - 6200
23/07/2020	+21 d	Keck	LRIS	400/3400	3200 - 5700
				400/8500	5500 - 10300
24/07/2020	+ 22 d	Gemini	GMOS-N	B1200	4400 - 6000
09/08/2020	+37 d	Shane-3m	KAST	B452/3306	3300 - 6200
				R300/7500	3300 - 6200
17/09/2020	+74 d	Keck	DEIMOS	B1200	4800 - 7400
12/02/2021	+212 d	Keck	LRIS	400/3400	3200 - 5700
				400/8500	5500 - 10300
12/05/2021	+296 d	Keck	LRIS	400/3400	3200 - 5700
				400/8500	5500 - 10300
08/07/2021	+350 d	Keck	LRIS	400/3400	3200 - 5700
				400/8500	5500 - 10300

Extended Data Table 3 | Photometry of AT 2020neh

MJD	Mag	Mag Err	Filter	MJD	Mag	Mag Err	Filter
59031.357	17.431	0.112	U	59039.449	17.928	0.105	B
59033.821	17.546	0.096	U	59045.027	18.558	0.131	B
59034.879	17.500	0.148	U	59047.956	18.984	0.153	B
59035.744	17.644	0.112	U	59053.724	18.966	0.154	B
59036.613	17.663	0.042	U	59055.714	19.282	0.179	B
59037.736	17.748	0.116	U	59057.244	19.501	0.169	B
59039.448	17.903	0.096	U	59061.764	19.332	0.165	B
59040.923	18.131	0.042	U	59066.542	20.239	0.189	B
59045.026	18.362	0.116	U	59084.468	19.834	0.191	B
59047.956	18.937	0.145	U	59033.826	17.668	0.171	V
59053.724	19.464	0.171	U	59039.455	18.001	0.161	V
59055.713	19.401	0.181	U	59055.720	18.229	0.183	V
59061.763	20.163	0.191	U	59031.359	17.637	0.072	UVW2
59066.541	19.758	0.177	U	59033.824	17.828	0.065	UVW2
59031.357	17.860	0.144	B	59034.880	17.897	0.102	UVW2
59033.822	17.686	0.111	B	59035.746	18.181	0.081	UVW2
59034.879	17.553	0.168	B	59037.738	18.533	0.092	UVW2
59035.745	17.787	0.129	B	59039.452	18.665	0.076	UVW2
59037.736	17.732	0.127	B	59045.030	19.527	0.102	UVW2

MJD	Mag	Mag Err	Filter	MJD	Mag	Mag Err	Filter
59047.959	20.771	0.144	UVW2	59039.460	18.483	0.071	UVM2
59049.026	19.995	0.193	UVW2	59045.037	19.433	0.100	UVM2
59053.727	20.389	0.131	UVW2	59047.965	20.088	0.124	UVM2
59055.717	20.958	0.146	UVW2	59049.029	19.982	0.180	UVM2
59057.247	20.706	0.143	UVW2	59053.734	20.598	0.136	UVM2
59061.767	21.303	0.160	UVW2	59055.724	20.512	0.128	UVM2
59066.544	21.384	0.158	UVW2	59057.253	20.529	0.132	UVM2
59068.064	21.550	0.160	UVW2	59063.765	22.293	0.170	UVM2
59070.188	20.697	0.171	UVW2	59066.551	20.907	0.147	UVM2
59074.114	20.885	0.177	UVW2	59068.071	21.105	0.146	UVM2
59078.425	21.898	0.174	UVW2	59070.193	20.981	0.165	UVM2
59084.471	23.592	0.187	UVW2	59078.431	21.426	0.164	UVM2
59086.263	22.616	0.178	UVW2	59080.365	21.569	0.162	UVM2
59088.989	21.792	0.184	UVW2	59082.490	22.157	0.164	UVM2
59031.363	17.463	0.066	UVM2	59084.477	21.445	0.155	UVM2
59033.827	17.826	0.135	UVM2	59086.269	22.335	0.174	UVM2
59034.882	17.922	0.101	UVM2	59031.356	17.417	0.085	UVW1
59035.751	17.949	0.073	UVM2	59033.819	17.675	0.078	UVW1
59037.743	18.268	0.083	UVM2	59035.743	17.967	0.097	UVW1
59038.735	18.548	0.063	UVM2	59037.735	18.064	0.100	UVW1

MJD	Mag	Mag Err	Filter	MJD	Mag	Mag Err	Filter
59039.446	18.228	0.084	UVW1	58968.429	21.027	0.202	PS1 r
59041.708	18.644	0.177	UVW1	58997.342	21.215	0.251	PS1 r
59045.024	18.941	0.110	UVW1	59037.367	17.989	0.046	PS1 r
59047.954	19.400	0.139	UVW1	59039.352	17.983	0.030	PS1 r
59053.722	20.051	0.166	UVW1	59053.281	18.435	0.038	PS1 r
59055.711	20.343	0.193	UVW1	59061.299	18.833	0.140	PS1 r
59057.241	20.411	0.179	UVW1	59065.275	18.767	0.042	PS1 r
59061.762	20.210	0.166	UVW1	59096.249	20.017	0.298	PS1 r
58958.530	21.095	0.306	PS1 g	59098.298	19.859	0.317	PS1 r
58968.426	21.241	0.254	PS1 g	58942.491	20.369	0.358	PS1 i
58990.375	21.282	0.287	PS1 g	58960.455	20.562	0.186	PS1 i
59021.287	18.962	0.051	PS1 g	58966.516	20.771	0.327	PS1 i
59024.381	17.964	0.020	PS1 g	58972.442	20.602	0.196	PS1 i
59027.278	17.727	0.026	PS1 g	58990.372	20.522	0.151	PS1 i
59053.284	18.615	0.041	PS1 g	59017.287	20.726	0.171	PS1 i
59071.274	19.453	0.163	PS1 g	59024.383	18.487	0.034	PS1 i
59106.237	20.490	0.259	PS1 g	59027.276	18.217	0.030	PS1 i
59115.231	20.633	0.225	PS1 g	59039.349	18.055	0.036	PS1 i
59024.381	17.970	0.020	PS1 g	59048.298	18.263	0.031	PS1 i
58958.533	20.786	0.201	PS1 r	59065.278	18.614	0.046	PS1 i

MJD	Mag	Mag Err	Filter	MJD	Mag	Mag Err	Filter
59065.278	18.598	0.045	PS1 i	59043.191	18.108	0.019	ZTF g
59071.271	18.886	0.103	PS1 i	59049.207	18.404	0.026	ZTF g
59096.252	19.265	0.156	PS1 i	59062.191	19.177	0.103	ZTF g
59106.234	19.479	0.092	PS1 i	59022.232	18.985	0.034	ZTF r
59037.364	18.308	0.079	PS1 z	59025.190	18.194	0.026	ZTF r
59061.302	18.840	0.170	PS1 z	59028.213	17.968	0.024	ZTF r
59098.295	19.519	0.294	PS1 z	59031.211	17.970	0.043	ZTF r
59115.228	19.719	0.187	PS1 z	59037.189	17.930	0.023	ZTF r
59019.255	20.667	0.145	ZTF g	59040.197	17.996	0.019	ZTF r
59022.199	18.755	0.032	ZTF g	59046.190	18.232	0.023	ZTF r
59025.231	17.879	0.021	ZTF g	59049.185	18.326	0.026	ZTF r
59028.201	17.716	0.020	ZTF g	59062.229	18.886	0.074	ZTF r
59031.189	17.631	0.029	ZTF g	59063.168	18.534	0.044	ZTF r
59034.195	17.688	0.030	ZTF g	59065.168	18.914	0.070	ZTF r
59040.232	17.913	0.017	ZTF g				