The Tidal Disruption Event AT 2018hyz II: Light Curve Modeling of a Partially Disrupted Star

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ABSTRACT
AT 2018hyz (=ASASSN-18zj) is a tidal disruption event (TDE) located in the nucleus of a quiescent E+A galaxy at a redshift of \( z = 0.04573 \), first detected by the All-Sky Automated Survey for Supernovae (ASAS-SN). We present optical+UV photometry of the transient, as well as an X-ray spectrum and radio upper limits. The bolometric light curve of AT 2018hyz is comparable to other known TDEs and declines at a rate consistent with a \( t^{-5/3} \) at early times, emitting a total radiated energy of \( E = 9 \times 10^{50} \) erg. The light curve shows an excess bump in the UV about 50 days after bolometric peak lasting for at least 100 days, which may be related to an outflow. We detect a constant X-ray source present for at least 86 days. The X-ray spectrum shows a total unabsorbed flux of \( \sim 4 \times 10^{-14} \) erg cm\(^{-2}\) s\(^{-1}\) and is best fit by a blackbody plus power-law model with a photon index of \( \Gamma = 0.8 \). A thermal X-ray model is unable to account for photons \( > 1 \) keV, while the radio non-detection favors inverse-Compton scattering rather than a jet for the non-thermal component. We model the optical and UV light curves using the Modular Open-Source Fitter for Transients (MOSFiT) and find a best fit for a black hole of \( 5.2 \times 10^6 \) M\(_{\odot}\) partially disrupting a \( 0.1 \) M\(_{\odot}\) star (stripping a mass of \( \sim 0.01 \) M\(_{\odot}\) for the inferred impact parameter, \( \beta = 0.6 \)). The low optical depth implied by the small debris mass may explain how we are able to see hydrogen emission with disk-like line profiles in the spectra of AT 2018hyz (see our companion paper, Short et al. 2020).

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1 INTRODUCTION
A tidal disruption event (TDE) can occur when a star gets too close to a supermassive black hole such that the tidal forces from the black hole exceed the self-gravity of the star, eventually tearing it apart (Hills 1975; Rees 1988). Following this disruption, the material from the star is expected to cir-
cularize into an accretion disk, and a fallback accretion phase begins, powering an optical transient (Gezari et al. 2009; Guillochon et al. 2009). There are about 60 known TDEs, showing a wide gamut of observational features (Auchettl et al. 2017; Mockler et al. 2019; van Velzen et al. 2020). Some exhibit hydrogen and helium emission, while others only helium (Gezari et al. 2012; Arcavi et al. 2014). More recently, TDEs with nitrogen and oxygen lines, powered by Bowen fluorescence, have been detected (Blagorodnova et al. 2019; Leloudas et al. 2019). van Velzen et al. (2020) defined three classes: TDE-H (hydrogen only), TDE-He (helium only) and TDE-Bowen (Bowen lines in combination with H and/or He). At least one TDE has evolved from showing hydrogen and Bowen lines to helium-only (Nicholl et al. 2019). Some TDEs show X-ray emission in excess of the optical luminosity, while others are X-ray dim (Holoien et al. 2016a; Auchettl et al. 2017). Additionally, radio observations suggest a few TDEs drive relativistic outflows, while others do not (Zauderer et al. 2011; Bower et al. 2013; van Velzen et al. 2013; Alexander et al. 2016).

In this paper we present radio, optical, UV, and X-ray observations of AT 2018hyz, originally discovered as a nuclear optical transient by the All-Sky Automated Survey for Supernovae (ASAS-SN; Shappee et al. 2014; Kochanek et al. 2017) on 2018 Nov 6 and designated ASASSN-18sx (Brinacombe & Stanek 2018). The transient was classified as a TDE on 2018 Nov 9 by Dong et al. (2018) and independently verified by Arcavi (2018) on 2018 Nov 12. van Velzen et al. (2020) first presented optical+Swift photometry of AT 2018hyz. The authors classify it as a TDE-H, one with broad Hα and Hβ lines. The early hydrogen-dominated spectrum transitions to being helium dominated (Short et al. 2020). The spectra are also blue and show broad double-peak emission lines that evolve in shape, from a smooth broad profile, to boxy, and then smooth again. For an in-depth description of the spectra see Short et al. (2020).

In §2 we present our follow-up observations and describe the publicly available observations of AT 2018hyz. In §3 we present our modeling of the light curve. In §4 we outline different properties of the light curves, and in §5 we describe the host galaxy of AT 2018hyz. In §6 we outline our key conclusions. Throughout this paper we assume a flat ΛCDM cosmology with H₀ = 69.3 km s⁻¹ Mpc⁻¹, Ωₘ = 0.286, and Ωₐ = 0.712 (Hinshaw et al. 2013).

2 OBSERVATIONS

2.1 Optical and UV Photometry

AT 2018hyz was first detected by ASAS-SN on 2018 Oct 14 with a magnitude of g = 17.08 ± 0.22 and a prior non-detection of g > 16.16 on 2018 Oct 10, with no previous deeper upper limits (Shappee et al. 2014; Kochanek et al. 2017). ASAS-SN observed AT 2018hyz regularly until 2019 Jun 27 and provided g and V band measurements of the source. The ASAS-SN photometry used in this work was obtained from the ASAS-SN Sky Patrol database ¹. We average the ASAS-SN photometry on bins of 1 day and only make use of the

¹ https://asas-sn.osu.edu/
the images using standard IRAF\(^2\) routines, and performed photometry with the daophot package. Instrumental magnitudes were measured by modeling the point-spread function (PSF) of each image using reference stars in the image. For calibration, we estimated individual zero-points of each image by measuring the magnitudes of field stars and comparing to photometric AB magnitudes from the PS1/3\(\sigma\) catalog. The uncertainties reported in this work are the combination of the photometric uncertainty and the zero-point determination uncertainty. To isolate AT 2018hyz from its host galaxy we perform image subtraction on each \(gr\) image using HOTPANTS (Becker 2015). We use archival PS1/3\(\sigma\) images as reference templates (Chambers & Pan-STARRS Team 2018); an example is shown in Figure 1.

All the ASAS-SN, UVOT, FLWO and Las Cumbres data were corrected for Milky Way galactic extinction using \(A_V = 0.0917\) mag, determined using the Schlafly & Finkbeiner (2011) dust maps. The photometry was then corrected to the rest frame from \(z = 0.04573\) and shifted in time to define phase 0 as the date of peak bolometric brightness, \(MJD = 58429\). All the optical-\(\nu\) photometry used for this work is shown in Figure 2 and 3. The individual FLWO, Las Cumbres, and UVOT data are available in machine-readable format in the online version of this journal and on the Open TDE Catalog \(^3\) (Guillochon et al. 2017).

2.2 Astrometry

AT 2018hyz is located in the nucleus of 2MASS J10065085+0141342, a galaxy at a redshift of \(z = 0.04573\) or a luminosity distance of 205 Mpc. We performed astrometry on an FLWO \(i\)-band image by cross-matching the positions of field stars in the image to the ICRS coordinates from Gaia-DR2 (Gaia Collaboration et al. 2016, 2018). We measure the centroid of AT 2018hyz on template subtracted images to be \(\text{R.A.} = 10^\text{h}06^\text{m}50.8^\text{s}, \text{decl.} = +01^\circ41'34''10"\) (J2000), with a centroid uncertainty of 0.03". We perform relative astrometry to measure the separation between AT 2018hyz and the center of its host galaxy. Using a pre-explosion template from archival PS1/3\(\sigma\) images as reference, and a template subtracted FLWO \(i\)-band image to measure the position of AT 2018hyz. The resulting offset is \(0''2 \pm 0''1\), equivalent to a physical separation of 0.2 \(\pm\) 0.1 kpc.

2.3 Radio and Millimeter Observations

We obtained millimeter observations with the Atacama Large Millimeter/submillimeter Array (ALMA) in Band 3 (~100 GHz) on 2018 November 28 and December 19 with a total on-source integration time of 22.2 minutes per epoch. We report the results of the ALMA data products which used J1058+0133 for bandpass and flux density calibration and J1010-0200 for complex gain calibration. The November 28 and December 19 epochs were imaged using 840 and 378 pixels, respectively, with an image scale of 0.13 and 0.29 arcsec per pixel, corresponding to a synthesized beam size of 0.81" \(\times\) 0.68" and 1.98" \(\times\) 1.47", respectively. The images were created using multi-frequency synthesis (MFS; Sault & Wieringa 1994), Briggs weighting with a robust parameter of 0.5, and a standard gridding convolution function. The source is not detected in either epoch with a 3\(\sigma\) limit of \(F_v (100\ GHz) \lesssim 37.6\) and 42.7\(\mu\)Jy for the November and December observations, respectively. This corresponds to a very low star formation rate of \(< 8.6 \times 10^{-6}\ M_\odot\ yr^{-1}\) (Kennicutt 1998).

Four hours of AMI-LA 15.5 GHz observations revealed no radio source at the location of the transient, corresponding to a 3\(\sigma\) upper limit of \(< 85\ \mu\)Jy on 2018 Nov 15 (Horesh et al. 2018). This upper limit corresponds to a luminosity \(\nu L_\nu < 6.6 \times 10^{-7}\ erg\ s^{-1}\), slightly deeper than the radio detections for ASASSN-14li, possibly a jetted TDE (van Velzen et al. 2016; Alexander et al. 2016). Our limits are comparable to some of the deepest radio upper limits for other TDEs, such as AT 2018zr (van Velzen et al. 2019a) and AT 2017egx (Nicholl et al. 2019), though shallower than iPTF16fnl (Blagorodnova et al. 2017); these had no detected radio counterparts.

ASASSN-14li has a ratio of total thermal energy to jet energy of \(10^{2.5}\) (van Velzen et al. 2016). If AT 2018hyz has a similar ratio, the total optical-\(\nu\) energy of \(< 10^{31}\) erg in AT 2018hyz would imply a jet energy of \(< 10^{28}\) erg. Our radio non-detection of AT 2018hyz suggests that any outflow may have been less energetic than that in ASASSN-14li; however, a lower ambient density or larger off-axis observing angle could also be responsible for the lower radio luminosity in this event.

2.4 X-ray Observations

AT 2018hyz was observed by the X-ray Telescope (XRT) onboard Swift (Burrows et al. 2005). We reduced the Swift-XRT data following the prescriptions by Margutti et al. (2013) with HEAsoft v6.26.1 and corresponding calibration.
files. We apply standard filtering criteria and bin the data into four separate epochs to estimate the source count-rate evolution with time. An X-ray source is detected in three epochs up to a phase of 86 days, while the source is not detected after binning all the data from a phase of 86 to 232 days. The upper limit obtained from the last bin is shallower than the previous detection and is therefore unconstraining, the flux-calibrated X-ray light curve is shown in Figure 3.

We do not find evidence for a statistically significant spectral evolution of the source. We extract a spectrum comprising the data at \( t < 86 \) days to constrain the spectral properties of the source and the count-to-flux conversion factor. We fit the 0.3–10 keV spectrum with a single absorbed power-law model with XSPEC and find a best fit photon index of \( \Gamma = 3.2 \pm 0.3 \) with no evidence for intrinsic absorption. We also fit the X-ray spectrum with a single blackbody and find a best fit temperature of \( T = 0.12 \) keV, this model is unable to account for high energy photons above \( > 1 \) keV, and is therefore disfavored.

In Figure 4 we show our preferred model, where we fit the spectrum with a blackbody component and an additional power law to account for the high energy photons. For this model we find a best fit to the blackbody component of \( T = 1.1 \pm 0.3 \) keV, and a photon index of \( \Gamma = 0.8 \pm 0.6 \). We adopt a redshift of \( z = 0.04573 \) and a neutral hydrogen column density along the line of sight to AT 2018bzy of \( N_{\text{H}} = 2.67 \times 10^{20} \) cm\(^{-2} \) (Kalberla et al. 2005). The total unabsorbed flux is \( 4.1^{+0.6}_{-0.4} \times 10^{-14} \) erg cm\(^{-2} \) s\(^{-1} \) (1σ errors). For this spectrum, the count-to-flux conversion factor is \( 6.16 \times 10^{-11} \) erg cm\(^{-2} \) counts\(^{-1} \).

Most TDEs show a decline in their X-ray light curve (Auchettl et al. 2017). Other TDEs, such as ASASSN-15oi, show a flat X-ray light curve with a subsequent late-time X-ray brightening, where the spectral shape and flat light curve of ASASSN-15oi were attributed to a likely AGN (Holoien et al. 2016b; Gezari et al. 2017). AT 2018fyk is another example of a TDE with a flat X-ray light curve with a subsequent brightening (Wevers et al. 2019). The X-ray luminosity of AT 2018bzy is not declining, but consistent with being flat. The X-rays in AT 2018bzy are also consistent with an AGN (Aird et al. 2015); given that the measured luminosity of \( \approx 3 \times 10^{41} \) erg s\(^{-1} \) is \( \sim 0.1 \% \) of the Eddington luminosity for the inferred black hole mass of \( \sim 10^{8} M_{\odot} \) (See §3 and Short et al. 2020 for a description of the mass estimates).

The ratio between the [O III] and hard (2–20 keV) X-ray luminosity functions of AGNs is \( 2.15 \pm 0.51 \) dex (Heckman et al. 2005). The host of AT 2018bzy has an archival spectrum from the Sloan Digital Sky Survey (SDSS), with emission line fluxes from the Portsmouth emission line Value Added Catalog (Thomas et al. 2013).

Using the power law component from our model for the X-rays with \( \Gamma = 0.8 \), and the host galaxy [O III] flux of \( 1.2 \pm 0.4 \times 10^{-16} \) erg cm\(^{-2} \) s\(^{-1} \), we find \( \log(L_{\text{X}}/L_{\text{OIII}}) = 2.2 \pm 0.2 \). This confirms the X-ray luminosity is consistent with an AGN, and that future temporal variability will be required to determine whether it is of AGN or TDE origin.

We compare the power-law index and luminosity of AT 2018bzy to the sample of sources from Auchettl et al. (2017), and see that AT 2018bzy is similar to other confirmed or likely X-ray TDEs. Auchettl et al. (2017) suggest that TDEs can separate into thermal TDEs without a jet, and non-thermal TDEs with a jet. Given the fact that AT 2018bzy has a non-thermal spectrum, that would be indicative of the presence of a jet, or inverse-Compton scattering of X-ray photons from the accretion disk. We fail to detect a jet in radio observations, but future temporal evolution will distinguish whether the X-ray emission is indeed dominated by the TDE or if it is a weak pre-existing AGN.

In Figure 5 we show a broadband SED with the X-ray spectra and best fit model compared to the optical photometry and radio upper limits. We do not account for
self-absorption in our extrapolation, however this is reasonable over this frequency range. ASASSN-14li showed a self-absorbed synchrotron spectrum with a peak that moved from ~20 GHz to ~2 GHz (Alexander et al. 2016), i.e. the turnover was at all times below the frequencies of our upper limits. The SED slope measured in radio observations of ASASSN-14li was $F_\nu \propto \nu^{-1}$ (compared to $F_\nu \propto \nu^{-0.2\pm0.6}$ for the X-ray model fit to AT 2018hyz). Using a steeper power-law more similar to ASASSN-14li would give a larger discrepancy between the model prediction and our radio upper limits. Thus the radio limits appear to favour a self-absorbed synchrotron spectrum with a peak that moved over the pericenter orbit of the star) is reparametrized in terms of the parameter $b$, due to the fact that this varies with the polytrope index of the star and the fraction of mass bound to the black hole. For stars $<0.3$ $M_\odot$, $M_{\text{SO}}$ assumes a polytropic index of $\gamma = 5/3$ (Mockler et al. 2019). A value of $b = 1$ represents a full disruption of the star, while $b = 0$ signifies no disruption. For AT 2018hyz we find a value of $b = 0.4$ ($\beta = 0.61$), making this the least disrupted star in the TDE sample of Mockler et al. (2019), with the next lowest value being $\beta = 0.84$ for TDE1.

Ryu et al. (2020) simulate a series of stars of different masses being disrupted by a 10$^6$ $M_\odot$ black hole, similar to the one in AT 2018hyz. The authors find that for a 0.15 $M_\odot$ star (their closest model to our best inferred mass of 0.1 $M_\odot$), an impact parameter of $\beta = 0.61$ corresponds to $>90\%$.

### Table 1

| Parameter | Prior | Best Fit | Units |
|-----------|-------|----------|-------|
| $\log(M_{\text{BH}})$ | [5, 8] | 6.72 ± 0.04 | $M_\odot$ |
| $M_\ast$ | [0.01, 10] | 0.100 ± 0.002 | $M_\odot$ |
| $\log(R_{\text{BH}})$ | [−4, 4] | 1.29 ± 0.04 | |
| $\log(T_\nu)$ | [−3, 5] | 0.151 ± 0.005 | days |
| $b$ | [0, 2] | 0.39 ± 0.03 | |
| $\beta^\dagger$ | | 0.61 ± 0.03 | |
| $I$ | | 0.92 ± 0.03 | |
| $\epsilon$ | | 0.10 ± 0.02 | |
| $\tau_{\text{exp}}$ | [−50, 0] | 13.1 ± 1.8 | days |
| $\log(n_{H,\text{host}})$ | [16, 23] | 17.6 ± 1.2 | cm$^{-2}$ |
| $\log\sigma$ | [−4, 2] | −0.74 ± 0.02 | |
| $A_V,\text{host}^\dagger$ | < 0.01 | | mag |

3 LIGHT CURVE MODELING

We model the light curves of AT 2018hyz using the TDE model in the MOSFiT Python package, a Markov chain Monte Carlo (MCMC) code designed to model the light curves of transients using a variety of different power sources (Guillochon et al. 2018). The TDE model in MOSFiT estimates the output luminosity by converting the input fallback rate of material from the disrupted star into radiation via an efficiency parameter. The model also takes into account a normalization and power-law exponent for the photosphere. An impact parameter determines whether the star was partially or entirely disrupted. And a viscous timescale defines how fast the accretion disk forms around the black hole. Lastly, to estimate the magnitude of the transient in each observed band, MOSFiT assumes a blackbody SED that is convolved with the passband of each filter. The full details of the TDE model are described in Mockler et al. (2019).

We run the MCMC using an implementation of the emcee sampler (Foreman-Mackey et al. 2013) and test for convergence by ensuring that the models reach a potential scale reduction factor of $<1.2$ (Gelman & Rubin 1992), which corresponds to about 2000 steps with 200 walkers. The best-fit parameters of the TDE model with the corresponding statistical 1σ confidence intervals on the fit are shown in Table 1. Figure 6 shows the best model realizations and Figure 7 shows the corresponding correlation among the most relevant parameters.

The uncertainties presented in this work represent only the statistical model uncertainties. Mockler et al. (2019) quantify the systematic uncertainties of the MOSFiT TDE model to be 0.66 dex for the mass of the star, and 0.2 dex for the mass of the black hole. These uncertainties come mostly from the uncertainty in the mass-radius relation assumed for the disrupted star.

From the MOSFiT model we derive an estimated disruption date of MJD = 58392 ± 2. We find the best model is that of a black hole of 5.2 × 10$^6$ $M_\odot$ partially disrupting a star of 0.1 $M_\odot$. A star is considered partially disrupted when a portion of the mass bound to the black hole is greater than half the total mass of the star. The impact parameter $\beta$ (the tidal radius over the pericenter orbit of the star) is reparametrized in MOSFiT in terms of the parameter $b$, due to the fact that this varies with the polytrope index of the star and the fraction of mass bound to the black hole. For stars $<0.3$ $M_\odot$, MOSFiT assumes a polytropic index of $\gamma = 5/3$ (Mockler et al. 2019). A value of $b = 1$ represents a full disruption of the star, while $b = 0$ signifies no disruption. For AT 2018hyz we find a value of $b = 0.4$ ($\beta = 0.61$), making this the least disrupted star in the TDE sample of Mockler et al. (2019), with the next lowest value being $\beta = 0.84$ for TDE1.
of the star surviving the disruption. For AT 2018hyz, this would correspond to a disrupted mass of $\lesssim 0.01 M_\odot$. For comparison, PS1-11af, a TDE that resulted from the partial disruption of a star (Chornock et al. 2014), has a $\beta = 0.90$ and a minimum stripped mass of $\sim 0.006 M_\odot$.

For a black hole mass of $10^{6.7} M_\odot$ disrupting a 0.1 $M_\odot$ star, the implied pericenter of the encounter is $R_p \sim 3 R_\star$ (or $9 R_\star$ for $M = 10^6 M_\odot$), given the impact parameter of $\beta = 0.6$. The hydrogen emission lines from the accretion disk imply an orbital radius of material emitting at $R \sim 600 R_\star$ (Short et al. 2020). The models of Bonnerot & Lu (2019) show that the size of the accretion disk in a TDE is $\sim \text{few} \times 10 R_p$. For AT 2018hyz, the observed emission lines are consistent with this model, but would point towards a smaller black hole mass.

Short et al. (2020) find a supermassive black hole mass of $\sim 10^{5-6} M_\odot$, obtained from assuming different M-$\sigma$ relations, lower than the mass estimate of $10^{6.7} M_\odot$ we obtain from MOSFiT. The peak bolometric luminosity of AT 2018hyz is $1.9 \times 10^{44}$ erg s$^{-1}$, corresponding to $\sim 0.3 L_{\text{Edd}}$ for a $10^{6.7} M_\odot$ black hole; this is a typical Eddington ratio for TDE light curve models (see Table 6 in Mockler et al. 2019).

4 OBSERVED PROPERTIES OF THE LIGHT CURVES

To obtain the bolometric light curve of AT 2018hyz we first bin the light curve on three day intervals to be able to generate individual SEDs for each epoch to which we fit a blackbody. For the bins that are missing one or more bands we estimate the missing value by interpolating the full light curves with a 5th or 6th degree polynomial in order to trace the non-monotonic structure of the light curves. We fit a blackbody to each epoch (Figure 8) to measure the bolometric temperature and radius. We estimate the flux outside the observed bands by extrapolating the blackbody fit. We then integrate the entire SED to generate a bolometric light curve. The resulting bolometric light curve, radius and temperature evolution are shown in Figure 9.

We calculate the total radiated energy of AT 2018hyz from a phase of 0 to 233 days to be $E = 6.3 \times 10^{50}$ erg, obtained by integrating the bolometric light curve shown in Figure 9. For the data before a phase of 0 days we lack color information, and therefore estimate the values of luminosity, radius, and temperature from the inferred MOSFiT models described in section 3. We estimate the total radiated energy before phase of 0 days to be $E \approx 2.5 \times 10^{50}$ erg. This gives a total radiated energy of $E \approx 9 \times 10^{50}$ erg for AT 2018hyz. Similarly, from fitting an empirical model to the light curve, van Velzen et al. (2020) find a peak luminosity of $L_{\text{bol}} \approx 4.35 \pm 0.01$, a mean temperature of $T \approx 4.25 \pm 0.01$, and a peak date of MJD$= 58428$.

We measure a peak temperature of $\sim 22,000$ K near phase 0, which decreases to $\sim 16,000$ K at a phase of 50 days, and then rises back up to $\sim 21,000$ K until a phase of 150 days (Figure 9). The TDE models from Mockler et al. (2019) show a similar increase in temperature at later times. Lodato & Rossi (2011) demonstrate that for an opaque radiatively-driven wind, photons are released at a photospheric radius much larger than the launching radius, and as the accretion rate decreases, the photosphere sinks in, and the corresponding temperature increases. A good example of this process might be the TDE ASASSN-14ae (Holoien et al. 2014), which shows a temperature evolution that resembles that of AT 2018hyz, shown in Figure 9.

In Figure 10 we show the bolometric light curve of AT 2018hyz as compared to other TDEs, and see that it is similar in luminosity and decline rate to some TDEs. The early time bolometric light curve (phase $< 50$ days) is well fit by a power law that falls as $L \propto t^{-5/3}$, the theoretical decline rate expected for TDEs (Rees 1988). After a phase of 50 days the bolometric light curve deviates from a $r^{-5/3}$ decline, and we see an excess bump that lasts for $\gtrsim 100$ days. The TDE ASASSN-15lh also shows an excess bump in the late time light curve, although much more pronounced than in AT 2018hyz (Leloudas et al. 2016). It should be noted that although ASASSN-15lh originated in the nucleus of a quiescent galaxy, it is a highly unusual event of uncertain nature, also suggested to be a superluminous supernova (Dong et al. 2016). Swift J1644+5734 is another TDE that shows a bump in its light curve $30-50$ days after peak, most prominent in bluer bands, same as for AT 2018hyz. AT 2018fyk also has a secondary optical bump (Wevers et al. 2019), where the authors suggest that the second bump might be powered by efficient reprocessing of X-rays from a variable super-
Eddington disk wind. One possible explanation for the excess bump in the bolometric light curve of AT 2018hyz is the mechanism outlined in Leloudas et al. (2016). Those authors suggest that the light curves of TDEs are powered by two mechanisms: circularization of the debris, and accretion onto the black hole. For the smaller supermassive black holes, it is hard to disentangle these two; but for the most massive black holes ($\gtrsim 10^7 M_\odot$), the accretion disk will be thin, increasing the viscous timescale, allowing accretion to be observed in the form of a secondary peak in the light curve.

It should also be noted that a late-time flattening of the UV light curves of TDEs has been observed for the smallest supermassive black holes $\lesssim 10^6.5 M_\odot$ (van Velzen et al. 2019b), marginally lower than the $10^6.7 M_\odot$ mass we estimate for AT 2018hyz. This flattening is likely due to an additional contribution of emission from the accretion disk and occurs on timescales of hundreds of days after disruption (van Velzen et al. 2019b), unlike in AT 2018hyz, where we observe the excess bump ~ 50 days after peak. Instead, the excess bump in AT 2018hyz could be produced by a sudden outflow of material; supported by the fact that the time of the excess bump coincides with the appearance of two spectral lines blueshifted from Hα and Hβ by ~ 12,000 km s$^{-1}$, respectively (Short et al. 2020). Additionally, the rise in temperature observed in AT 2018hyz corresponds to the emergence of He II lines in the spectra, which develop after a phase of ~ 70 days and were suggested to be related to an outflow or material colliding debris (Short et al. 2020). If this is the case for AT 2018hyz, it would be late compared to outflows launched from other TDEs. For comparison, ASASSN-14li showed an outflow which was estimated to be launched 20-30 days before its bolometric peak (Alexander et al. 2016).

Adopting a total disrupted mass of 0.01 $M_\odot$ and a photospheric blackbody radius of 1.25 x $10^{15}$ cm during the light curve peak (Figure 9), we measure the average density of material behind the photosphere to be $\rho \approx 5 \times 10^{-15}$ g cm$^{-3}$, which implies an optical depth $\tau \approx 0.8$ (for an opacity dominated by electron scattering in ionized hydrogen $\kappa = 0.34$ cm$^2$ g$^{-1}$). At later times, after the photosphere contracts to $3 \times 10^{14}$ cm, the corresponding optical depth is $\tau \approx 18$. The low optical depth at early times might allow us to peer deep into the TDE, allowing us to see disk signatures (double-peaked Balmer emission lines) more clearly than in other TDEs (Short et al. 2020). The increasing optical depth may help to explain why we no longer see disk-like line profiles beyond ~ 100 days.

5 HOST GALAXY

From an archival SDSS spectrum, we see that AT 2018hyz is found in the nucleus of a quiescent E+A galaxy (Short et al. 2020). It is unsurprising to see a TDE in this galaxy, since it has been shown that TDEs tend to be over-represented in these types of galaxies by a factor of 30 ~ 35 (Arcavi et al. 2014; French et al. 2016; Graur et al. 2018). van Velzen et al. (2020) modeled the host galaxy with Prospector (Leja et al. 2017) and find a host mass of $\log (M/M_\odot) = 9.84^{+0.09}_{-0.14}$, a stellar population age of 4.74$^{+1.98}_{-1.40}$ Gyr and a metallicity of $Z/Z_\odot = -1.41^{+0.44}_{-0.37}$.

We model the host’s SED in order to derive its magnitude in the UVOT bands. We generated $3.9 \times 10^6$ templates.
based on the Bruzual & Charlot (2003) stellar population-synthesis models with the Chabrier initial mass function (IMF; Chabrier 2003). The star formation history (SFH) was approximated by a declining exponential function of the form \( \exp(-t/\tau) \), where \( t \) is the age of the stellar population and \( \tau \) the e-folding time-scale of the SFH (varied in nine steps between 0.1 and 30 Gyr). These templates were attenuated with the Calzetti et al. (2000) model that we varied in 22 steps from \( E(B - V) = 0 \) to 1 mag. The best-fitting templates were identified from \( \chi^2 \) minimization. Excluding NIR photometry (due to contamination by a nearby red star), we find a mass log \( (M/M_\odot) = 9.40^{+0.16}_{-0.12} \) in broad agreement with van Velzen et al. (2020), and negligible current star formation. The limits on star formation rate of \( <8.6 \times 10^{-6} \ M_\odot \text{yr}^{-1} \) placed by our ALMA non-detections rule out obscured star-formation, in agreement with the current classification as an E+A galaxy and the lack of star-formation inferred from our model fit. We convolve the SED of the best-fitting templates with the UVOT passbands to derive the estimated magnitude of the host in these bands, shown in Table 2.

6 CONCLUSIONS AND DISCUSSION

AT 2018hzy is a tidal disruption event found in the nucleus of a quiescent E+A galaxy at a redshift of \( z = 0.04573 \). We presented optical and UV photometry of AT 2018hzy from UVOT, ASAS-SN, FLWO, and Las Cumbres, representing one of the best sampled TDE light curves in the literature (in addition to densely sampled spectroscopic observations, presented in Short et al. 2020), allowing us to study its evolution in detail.

We modeled the light curves using MOSFiT and find a best fit for a \( 5.2 \times 10^6 \ M_\odot \) black hole partially disrupting a 0.1 \( M_\odot \) star. Comparing to models of other TDEs we find AT 2018hzy to have the least disrupted star in the known sample, with an impact parameter of just \( \beta = 0.61 \). This corresponds to an inferred total disrupted mass of \( \lesssim 0.01 \ M_\odot \). A low disrupted mass may produce a low optical depth, which in turn allows us to see the accretion disk spectra with less reprocessing than other TDEs, which we observe in the form of double peaked hydrogen emission lines (Short et al. 2020).

We detect an excess bump in the bolometric light curve after a phase of 50 days, most prominent in the UV, which could be due to a sudden outflow of material or reprocessing of X-rays into optical/UV radiation. This is consistent with the emergence of He II lines in the spectra and an increase in the bolometric temperature.

An X-ray source is detected up to a phase of 86 days, consistent with having a constant luminosity. The X-ray spectra can not be explained by a simple blackbody, but instead we find a best fit to an absorbed blackbody plus power-law model with a photon index of \( \Gamma = 0.8 \pm 0.6 \). A non-thermal X-ray spectrum is expected for jetted TDEs. Extending the power-law component of the X-ray model to radio wavelengths predicts a radio flux in excess of our limits (\( \lesssim 13 \ \mu \text{Jy} \)), thus the non-detection in the radio seems to favour inverse-Compton scattering for the non-thermal X-rays.

We consider three possible origins for the X-ray emission: the TDE itself, a pre-existing AGN, or star-formation. The latter can be excluded due to the negligible ongoing star-formation inferred from our radio data and host SED fitting. The X-rays could be consistent with a weak AGN given the measured luminosity, but temporal evolution in future deep X-ray observations will allow us to determine the nature of the X-ray emission.

The rich dataset we have presented and the finding of a very low disrupted mass indicates a new way to account for the diversity in observed TDEs.

| Value | Units |
|-------|-------|
| NUV   | 21.57 ± 0.26 mag (GALEX) |
| u     | 19.06 ± 0.04 mag (SDSS)  |
| g     | 17.49 ± 0.01 mag (SDSS)  |
| r     | 17.46 ± 0.01 mag (SDSS)  |
| i     | 16.96 ± 0.01 mag (SDSS)  |
| z     | 16.71 ± 0.02 mag (SDSS)  |
| y     | 15.55 ± 0.01 mag (SDSS)  |
| V     | 16.51 ± 0.01 mag (SDSS)  |
| B     | 16.44 ± 0.01 mag (SDSS)  |
| U     | 17.087 model mag          |
| UVM1  | 17.736 model mag          |
| UVM2  | 19.124 model mag          |
| UVW1  | 20.726 model mag          |
| UVW2  | 21.312 model mag          |

Figure 10. The bolometric light curve of AT 2018hzy is shown in green. The corresponding bolometric light curve models of all other well-observed TDEs from the Mockler et al. (2019) sample are shown for comparison. The black dashed line is a \( 5/3 \) fit to the early time data (phase < 50 days) of AT 2018hzy, showing a clear excess bump in the late time light curve.
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