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Discovery and Follow-up of the Unusual Nuclear Transient OGLE17aaj


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ABSTRACT

Aims. We report on the discovery and follow-up of a peculiar transient, OGLE17aaj, which occurred in the nucleus of a weakly active galaxy. We investigate whether it can be interpreted as a new candidate for a tidal disruption event (TDE).

Methods. We present the OGLE-IV light curve that covers the slow 60-day-long rise to maximum along with photometric, spectroscopic, and X-ray follow-up during the first year.

Results. OGLE17aaj is a nuclear transient exhibiting some properties similar to previously found TDEs, including a long rise time, lack of colour-temperature evolution, and high black-body temperature. On the other hand, its narrow emission lines and slow post-peak evolution are different from previously observed TDEs. Its spectrum and light-curve evolution is similar to F01004-2237 and AT2017bgt. Signatures of historical low-level nuclear variability suggest that OGLE17aaj may instead be related to a new type of accretion event in active super-massive black holes.

Key words. Black hole physics – Galaxies: nuclei – Galaxies: individual: GALEXASC J015624.70-710415.8, OGLE17aaj.

1. Introduction

Transients in the centres of galaxies are challenging to discover and study. However, an increasing number of such flares is being detected by wide-field sky surveys, such as iPTF (Blagorodnova et al. 2017), Pan-STARRS (Lawrence et al. 2016), and OGLE (Wyrzykowski et al. 2017). A variety of flaring mechanisms have been suggested to explain these discoveries, which range from supernovae, changing-look active galactic nuclei (AGN; e.g. LaMassa et al. 2015), extreme AGN flares of unclear nature (e.g. Graham et al. 2017), or tidal disruption events (TDEs). A TDE occurs when a star passing near a super-massive black hole (SMBH) residing in the centre of a galaxy is disrupted by tidal forces. Roughly half of the material of the disrupted star forms an accretion flow around the SMBH (Rees 1988). The interaction of the matter in the accretion flow produces a bright, blue flare that lasts from months to years. For SMBHs with mass \( M \approx 10^6 M_\odot \), the flare amplitude is expected to be an order of mag-
The transient AU 2017bgt was detected at a host-subtracted $I$-band magnitude of about $21^{m}$ and reached an $I$-band maximum of $20^{m}$ in about 60 days (Fig. 1). The transient then declined for about 200 days and appears to subsequently have reached a plateau. The UV measurements follow the trend seen in optical observations. At maximum, the transient reached $m_{UVW1} = 19^{m}06$ and $m_{UVW2} = 18^{m}52$ on galaxy-subtracted Swift images, which corresponds to an increase in UV flux by a factor of ~16 compared to archival GALEX measurements. The estimated peak absolute magnitude of OGLE17aaj in the $I$ band is $M_I = -18^{m}8$. Because the transient is not yet completed, we can derive the lower limit on the total energy emitted until now as about $7 \times 10^{33}$ ergs, which corresponds to a lower limit of the accreted mass of $M_{\text{acc}} \approx 0.04 M_{\odot}$, assuming a radiating efficiency of 0.1.

The UV source associated with the host galaxy is listed in the GALEX catalogue (Bianchi et al. 2011) as GALEX-ASC J015624.70–710415.8, with far-UV (FUV) AB magnitudes of $21^{m}414 \pm 0^{m}305$ and near-UV (NUV) $21^{m}183 \pm 0^{m}172$. No X-ray sources are detected in the ROSAT all-sky survey (Boyle et al. 2016) in the vicinity of this galaxy. No radio catalogues are comparable in depth to the ATCA post-outburst observations (non-detection at the 50 µJy level at 5 and 9 GHz; Stanway et al. 2017) cover this region of the sky. The deepest surveys are the AT20G survey, conducted at 20 GHz with ATCA (flux-density limit of 40 mJy; Murphy et al. 2010) and the GLEAM survey at 72–231 MHz with the Murchison Widefield Array (50 mJy; Hurley-Walker et al. 2017). The host was measured by the Wide-Field Infrared Survey Explorer, W1=15.113±0.030, W2=14.889±0.046, W3=12.089±0.023, and W4=8.953 (AllWISE; Wright et al. 2010) and Cutri et al. 2013). Photometric data for this galaxy can also be found in the USNO-B1.0 catalogue (Monet et al. 2003). We used these archival data, that is, broad-band magnitudes from GALEX, USNO-B1.0, and AllWISE, to estimate the spectral energy density (SED) of the host before the appearance of the transient (following Kozłowski et al. 2015). The absolute magnitude of a TDE in the optical can be very bright and may reach $M = -20$ or even up to $M = -23$ (Arcavi et al. 2014; Udalski et al. 2016). However, the recent discovery of the fast and faint event iPTF16nli (Besagorodnova et al. 2017) suggests that the population might also extend to fainter peak magnitudes.

The estimated TDE rate is about one per $10^4 - 10^5$ years per galaxy (Wang & Liu 2016; Stone & Metzger 2016). However, most optically selected TDEs have been discovered in post-starburst (E+A) galaxies (Arcavi et al. 2014), which are elliptical galaxies with an atypically large population of young A-type stars. It is not clear whether these rates also apply to other types of hosts, as some recent TDE candidates have been found in different types of galaxies: in weak AGN (OGLE16aa; Wyrzykowski et al. 2017) or ultra-luminous infrared galaxies (ULIRGs; Tadhunter et al. 2017; Mattila et al. 2018). These discoveries show that our current knowledge of TDE demographics is far from complete.

We here report the discovery and early follow-up of a nuclear transient, OGLE17aaj, which shares spectral features with AT 2017bgt (Guillochon & Ramirez-Ruiz 2015). The absolute magnitude of OGLE17aaj in the $I$-band, respectively. At maximum, the transient reached $m_{UVW1} = 19^{m}06$ and $m_{UVW2} = 18^{m}52$ on galaxy-subtracted Swift images, which corresponds to an increase in UV flux by a factor of ~16 compared to archival GALEX measurements. The estimated peak absolute magnitude of OGLE17aaj in the $I$ band is $M_I = -18^{m}8$. Because the transient is not yet completed, we can derive the lower limit on the total energy emitted until now as about $7 \times 10^{33}$ ergs, which corresponds to a lower limit of the accreted mass of $M_{\text{acc}} \approx 0.04 M_{\odot}$, assuming a radiating efficiency of 0.1.
To fit the SED, we used the low-resolution templates of AGN and galaxies from [Assef et al. (2010)]. The best-matching template to explain the observed SED comprised an elliptical galaxy plus an AGN, but the residuals of the host light Sérsic model fit with GALFIT (Peng et al. 2010) indicate weak spiral arms.

The classification spectrum, taken ten days after maximum (Fig. 2), revealed a flat continuum with many prominent emission lines: hydrogen Balmer lines, He i λ5876, He ii λ4686, [O iii] λ4960, 5007, [O ii] λ3727, and [S ii] λ6718, 6732. The lines are at a redshift of z = 0.116, which corresponds to a luminosity distance of 540 Mpc. The spectrum looks very similar to the spectra of F01004-2237 from September 2015, that is, to spectra taken around five years after its maximum, when the transient was still ongoing. The shape of the line complex around He ii λ4686 in particular is very similar (see Fig. 2). It has a double-peaked structure, where the bluer broad component can be associated with N ii λ6460, or blue-shifted He ii. The FWHM of the combined double feature, ~5000 km s$^{-1}$, is also very similar in both objects. The line ratio of (N ii+He ii)/Hβ = 0.9 is twice lower than in F01004-2237, while typical quasars have ~0.02 (Vanden Berk et al. 2001).

During the first two months of spectroscopic follow-up, the spectrum of OGLE17aaj essentially remained stable. The equivalent widths of the emission lines varied at a level of 20 percent. However, it is unclear whether these are caused by real, astrophysical effects or by the varying quality of the spectra, which were usually taken at high air masses (1.7-2). After a seasonal gap, we took another SALT spectrum, in which the double-peak profile around He ii disappeared and only one emission feature remained. This spectrum also shows a decrease in the flux of the Hβ and Hα emission lines (by a factor of 3 and 1.5, respectively). We were unable to compare the SALT +226d spectrum with previous VLT spectra in detail because SALT used a slit that is twice as wide, and therefore the contribution from host emission was more significant. We took an additional VLT spectrum with the same configuration as the first, which shows that the intensities of He ii and Hα decrease by a factor of ~3, and Hβ practically disappeared. We also attempted to estimate the position of the host on the BPT diagnostic diagram, but because our spectra contain both the host and transient, the line measurements were strongly affected by the transient, which increased the flux in hydrogen lines. Such measurement will be possible after the transient is completed.

The shape of the continuum is rather flat, although Swift colours suggest a high temperature of ~20 000 K, and it recalls those in Seyfert type II galaxies. The main difference is the presence of N ii+He ii emission, and the Balmer emissions are also much stronger. Most likely, an underlying, persistent AGN continuum contributes to the optical spectrum, and the difference imaging therefore merely shows that the variable component of this flat continuum is blue. A behaviour like this is also seen in variable AGN (e.g. Hung et al. 2016).

A weak X-ray source is detected at the 4σ confidence level in the stacked Swift/XRT image at the position of the transient, with a net count rate of 0.0011±0.0003 cts/s. When we fix the H i column density to the Galactic value along this line of sight (5.53 × 10$^{20}$ cm$^{-2}$; Bajaja et al. 2005; Kalberla et al. 2005), the spectrum can be fitted by an absorbed power law with a photon index of 2.5 ± 0.6 and an intrinsic 0.3–10 keV flux of 4.5 × 10$^{-14}$ ergs cm$^{-2}$ s$^{-1}$. The corresponding intrinsic luminosity in this band is 1.57 × 10$^{42}$ ergs s$^{-1}$. The flux estimation uncertainty is about 40%. The [O iii] λ5007 to Hα X-ray ratio is consistent with what is typically seen in X-ray detected, low-redshift AGN (e.g. Berney et al. 2015 and references therein).

No detectable X-ray emission is found in individual observations with a typical upper limit of 0.002 cts/s (8×10$^{-14}$ ergs cm$^{-2}$ s$^{-1}$). Taking into account the Galactic reddening of E(B−V) = 0.025 (Schlafly & Finkbeiner 2011), we estimated the colour temperature (Fig. 1, bottom panel) using the three Swift/UVOT ultraviolet filters, where the host light contribution is minimal. We estimated the mass of the SMBH using the properties of the
host galaxy based on the pre-transient imaging. The fraction of the light from the bulge with respect to the total flux emitted by the galaxy, measured with GALFIT on a deep stack of V-band archival OGLE images, is 19.8%, which yields log $M_{BH} = 7.37$ using the method of Bentz et al. (2009).

Additionally, the archival OGLE-IV V-band light curve, covering six years before the transient, shows a small-scale irregular variability at a level of 10%, which is significantly lower than the flare itself (Fig. 3) and indicates on-going accretion onto the SMBH.

4. Discussion

The UV and optical light curves of OGLE17aaj indicate no or slow colour-temperature change over the entire monitoring period. Temperatures as high as 4 x $10^4$ K at maximum are not typical of supernovae, but are seen in TDEs (e.g. Gezari et al. 2012, Arcavi et al. 2014). The peak absolute magnitude of OGLE17aaj ($M_V = -18.8$) is fainter than in most known optical TDEs and exceeds $-20^m$. Nevertheless, it is not the first example of such a faint event, as the faint TDE iPTF16fnl reached only $M_V = -17.2$ (Blagorodnova et al. 2017).

The light curve from OGLE-IV shows a well-covered, smooth, and long-duration rise to maximum. Most of the TDEs reported so far hardly ever had such a good pre-discovery coverage. While the slow rise of OGLE17aaj could still be in agreement with an interpretation as a TDE, the decline is much slower (about 0.5 mag/year). In particular, the flattening of the light curve after 200 days has never been seen in any TDE. The light curve of OGLE17aaj is somewhat similar to the changing-look AGN SDSS J233317 (MacLeod et al. 2016), but the spectrum of that object does not have the characteristic He $\lambda$ II+N $\lambda$ feature seen in OGLE17aaj. This suggests that OGLE17aaj may be related to a change in the state of the AGN rather than a TDE.

A broad ($\sim 30,000$ km s$^{-1}$) He $\lambda$ line component is the most typical feature of most TDEs (e.g. Arcavi et al. 2014). However, in the case of OGLE17aaj, this emission line is significantly narrower at $\sim 5000$ km s$^{-1}$. The He $\lambda$ profile is irregular and is very similar to what is seen in the F01004-2237 event five years after its maximum (Tadhunter et al. 2017). The complex feature around He $\lambda$ (4686 in F01004-2237) was explained with a large population of $\sim 10^4$ Wolf-Rayet stars (WR), and with an additional blue-shifted helium line with an FWHM $\sim 6200$ km s$^{-1}$, which, according to Tadhunter et al. (2017), originated from a TDE.

The host of OGLE17aaj shows weak levels of AGN activity. In contrast to F01004-2237, it has a negligible WR population. However, the similar optical spectra and the slow photometric evolution suggest that they may be driven by a similar phenomenon. We note that the estimated black hole mass for the SMBH we associate with OGLE17aaj is an order of magnitude lower than in the case of F01004-2237. Both the archival photometric variability of the nucleus and narrow lines in the spectrum originating from the host indicate that the nucleus of the galaxy is active at a low level. If the SMBH has been accreting in the past, the observed greater change in brightness fits the overall picture of a rapid change in the accretion rate.

Recently, Trakhtenbrot et al. (2019) have reported the discovery of the transient AT 2017bgf, which showed optical features that are very similar to those seen in OGLE17aaj, as well as a similar photometric evolution. High-quality near-IR and optical spectra of AT 2017bgf showed single-peaked He $\lambda$ II lines, which rules out a disk origin for the double-peak profile in the broad feature associated with He $\lambda$ II 4686, and thus suggests that the bluer peak originates from N $\lambda$ 4640. They also identified several blue O $\lambda$ lines and argued that the O $\lambda$ and N $\lambda$ features are produced by the Bowen fluorescence mechanism, which is driven by enhanced accretion of gas onto an existing AGN. This further disfavours a TDE.

5. Conclusions

We reported the discovery and early follow-up observations of the unusual nuclear transient OGLE17aaj. We investigated it as a potential TDE candidate based on its high black-body temperature and on the similarity of its spectrum to that of the recently reported nuclear event in F01004-2237, which was interpreted as a TDE (Tadhunter et al. 2017). The narrow spectral features of the host and pre-flare photometric variability might instead indicate that these types of events represent a change in the accretion flow of AGN. OGLE17aaj showed a well-covered 60-day-long rise and a slow 200-day decline, followed by a plateau until day 300. This is unlike any TDE reported so far.

The discovery of OGLE17aaj, as well as other similar transients with high amplitudes in AGN, indicates that a new class of AGN-related phenomena exist. It may lead to new ways of investigating the close environments of SMBHs and the accretion flows through which they grow.

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References

Burrows D. N., et al., 2005, SSRv, 120, 165
Cutri, R. M., & et al. 2013, VizieR Online Data Catalog, 2328,
Gromadzki, M., Hamanowicz, A., & Wyrzykowski, Ł. 2017, The Astronomer’s Telegram, 9977
Kozłowski, S. 2015, Acta Astron., 65, 251
Mattila S. et al., 2018, Science, eaao4669
Roming P. W. A., et al., 2005, SSRv, 120, 95
Tadhunter, C., Spence, R., Rose, M., Mullaney, J., & Crowther, P. 2017, Nature Astronomy, 1, 0061
Wang, X.-Y., & Liu, R.-Y. 2016, Phys. Rev. D, 93, 083005