Flares from centres of galaxies – OGLE-Gaia hunt for tidal disruption events

Mariusz Gromadzki[1], Łukasz Wyrzykowski[1], Aleksandra Hamanowicz[1], Krzysztof Rybicki[1], Nada Ihanec[2] and Kirill V. Sokolovsky[3·4·5]

1. Astronomical Observatory University of Warsaw, Al. Ujazdowskie 4, 00–478 Warszawa, Poland
2. School of Science, University of Nova Gorica, Vipavska 11c, 5270 Ajdovščina, Slovenia
3. IAASARS, National Observatory of Athens, Vas. Pavlou & I. Metaxa, Penteli 15236, Greece
4. Sternberg Astronomical Institute, Moscow State University, Universitetsky pr. 13, Moscow 119991, Russia
5. Lebedev Physical Institute, Astro Space Center, Profsoyuznaya 84/32, Moscow 117997, Russia

When a star gets too close to a super-massive black hole in the centre of a galaxy, it can get disrupted and partially consumed by the black hole. Such tidal disruption events (TDE) exhibit as a bright, blue and hot flares detectable in the cores of galaxies and trace population and masses of SMBHs. We present our long-term project to study the demographics of SMBHs via TDEs. We relied on transients detected primarily by OGLE and Gaia surveys, which are then followed-up by ESO, SALT, NOT as well as space telescopes. We show our first candidates for TDEs, in most case not typical, indicating there is still little known about processes in the centres of galaxies.

1 Introduction

Tidal Disruption Event (TDE) happens when a hapless star falls within the tidal radius of a super-massive black hole (SMBH) in the centre of a galaxy. If the tidal radius is smaller than the event horizon of the black hole, such act of butchery can be seen from afar as a bright, blue and hot flare, detectable in the core of galaxy. Discoveries of TDEs can help trace the population and masses of black holes in the centres of galaxies, including intermediate mass black holes. However, transients occurring in the galactic nuclei are challenging to find and classify due to the strong contamination from their host galaxy. Here we report on our on-going project to systematically search for nuclear transients in OGLE and Gaia Surveys in real-time and archival data.

2 Data

In this work the search for the nuclear transients is based primarily on the OGLE–IV Transient Detection System (Kozłowski et al., 2013; Wyrzykowski et al., 2014b) and Gaia Science Alerts (Wyrzykowski & Hodgkin, 2012; Wyrzykowski et al., 2014a; Hodgkin et al., 2013), reported in the period from mid-2016 until mid-2017. Additionally, we also studies archival OGLE data from 2010-2016 (Hamanowicz et al., 2018, in prep.).

OGLE-IV (Udalski et al., 2015) has a dedicated sub-survey for transients, which regularly monitors about 700 deg^2 around the Magellanic Clouds and detects transients up to 21 mag in I-band. The search pipeline, based on the Self Organising

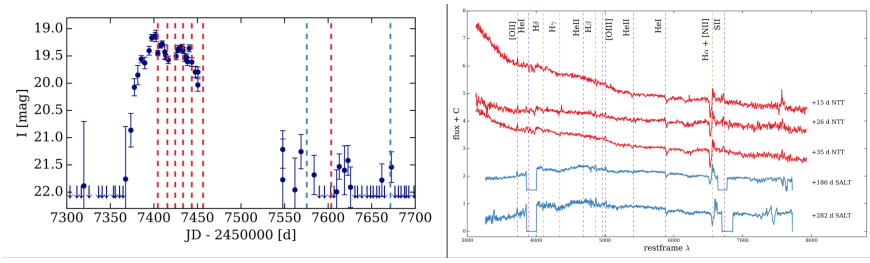

Fig. 1: Photometry and spectroscopy of OGLE16aaa, TDE candidate. The vertical lines indicate moments of spectral observations.

Maps machine learning algorithm, is relaying on only one image and can produce candidate alerts within 15 minutes after observation (Klencki et al., 2016). The transients are available on the webside[1].

Additionally, we identified about 6 million galaxies within the surveyed area on deep stacks of OGLE images (about 100 images) reaching to ~ 24 mag in I-band, and extracted difference imaging photometry of their centres. The transients found in this way, were mostly already gone, as the data have covered years 2010-2016. However, it was still interesting to investigate the properties of their host galaxies in order to figure out the nature of these past transients.

Gaia Science Alerts. Gaia is a space mission operating since 2014. It is collecting photometric time-series from all over the sky (70 on average over its nominal 5 years), which allowed Gaia to detect transients down to 20.5 mag (Wyrzykowski & Hodgkin, 2012). The Science Alerts system (Hodgkin et al., 2013) operates in the Institute of Astronomy in Cambridge and provides candidates for transients within 1-2 days from its observation from space. Until the end of 2017, Gaia has been reported more than 3000 transients, mostly supernovae, but also cataclysmic variables and microlensing events (Wyrzykowski et al., 2018; Kruszyńska et al., 2018, in prep.). In the near future Gaia's superb astrometry will allow identification of nuclear transients with astrometric accuracy of about 1 mas (compared to current 50 mas). Additionally, Gaia provides low-resolution spectra for each observation, which help to recognise main types of transients without expensive spectroscopic follow-up (Blagorodnova et al., 2014). The alerts are available on the webside[2].

Spectroscopic classification and follow-up. In the North Sky we used 2.5 m NOT located on La Palma, as part of the NOT Unbiased Transient Survey (NUTS, PI: Mattila). On the southern sky we used Public ESO Spectroscopic Survey for Transient Object (PESSTO) with 3.5 m ESO/NTT in La Silla. We also took part in the SALT Large Program *Observing the Transient Universe* (PI: D. Buckley) conducted on 11 m SALT telescope with Long slit Robert Stobie Spectrograph (RSS) instrument. For the most demanding objects, we used ToO time on ESO VLT (proposal of L.Wyrzykowski no 098.B–0768/A and M.Gromadzki no 0100.B-0503/A), with 8.2 m primary mirror and instrument FORS2 (FOcal Reducer/low dispersion Spectrograph).

[1] http://ogle.astrouw.edu.pl/ogle4/transients/
[2] http://gsaweb.ast.cam.ac.uk/alerts

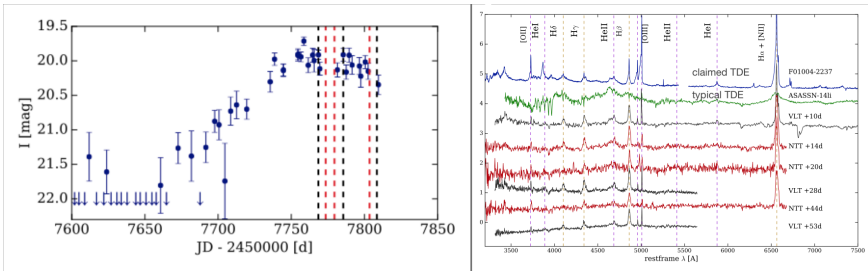

Fig. 2: Photometry and spectroscopy of OGLE17aaj, TDE or unusual AGN flare.

3 Results

OGLE16aaa - TDE. Transient with a very long rise to the maximum and slow decline, reaching $M = -20.5$ mag at maximum, with redshift $z = 0.166$. Spectrum showed very broad HeII and H emission lines over the blue continuum. UV colour indicated that the flare reached 22,000 K and the temperature stayed constant over months. Host galaxy of OGLE16aaa is a weak AGN, indicating previous activity of the black hole.

OGLE17aaj - TDE candidate - or unusual AGN flare? It also had a long unusual rise to the maximum in about 60 d, but reaching only $M = -18.8$ mag ($z = 0.116$), similarly to faint TDE candidate iPTF16fnl (Blagorodnova et al., 2017). Swift UV photometry showed hot black-body temperature 20,000 K. The spectrum showed a complex HeII feature plus extra broad component, similar to TDE in F01004-2237 (Tadhunter et al., 2017) and ASASSN-17cv/17bgt (Trakhenbrot et al., 2018, submitted). It belongs possibly to the unknown class of TDEs or it is an unusual AGN flare (Gromadzki et al., 2018, submitted).

Gaia16apt - AGN? The slowly rising nuclear flare with very broad Balmer emission lines typical for AGN and blue continuum was observed, with no spectral changes detected half a year later. Continuous rise in brightness: amplitude over 1 mag is atypical for AGNs.

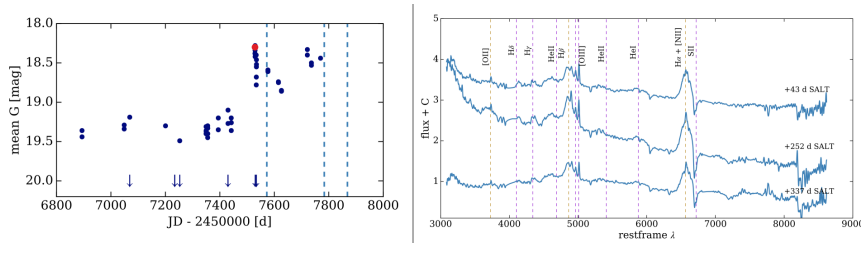

Fig. 3: Photometry and spectroscopy of a nuclear candidate Gaia16apt, a huge AGN flare.

OGLE15gt - Type IIn SN displays very long lightcurve (2 years) reaching -19 mag in I-band. The spectra show dimming Balmer fairly broad emission lines (similar to Changing-Look AGNs) on top of host lines. This matches a supernova Type IIn lightcurve, where the emission originates from the circumstellar material.

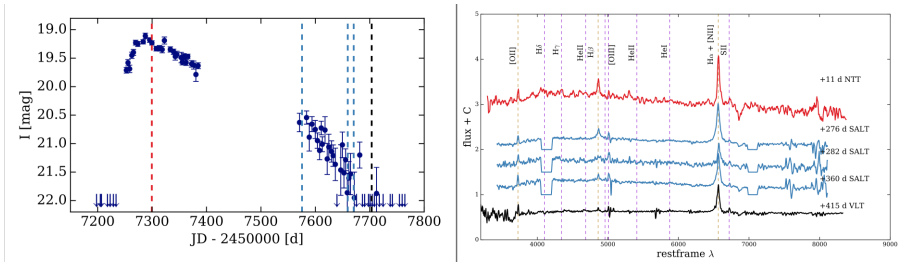

Fig. 4: Photometry and spectroscopy of nuclear transient, OGLE15gt, supernova Type IIn.

4 Conclusions

We investigated in detail 27 nuclear transients from OGLE and Gaia, reported in 2016-2017 with spectroscopy on the largest telescopes in the world. Among discovered objects we found candidates for TDEs and a number of supernovae of various types and unusual AGN flares.

Acknowledgements. We thank OGLE and Gaia teams for providing excellent data which enables discovery of interesting transients. This work has been supported by Polish National Science Center grant OPUS No. 2015/17/B/ST9/03167 to ŁW, as well as OPTICON H2020 EC grant No. 730890.

References

Blagorodnova, N., et al., *MNRAS* **442**, 327 (2014)

Blagorodnova, N., et al. (2017), `arXiv: 1703.00965`

Gromadzki, M., Wyrzykowski, H. A., Ł., Gromadzki, M., Wyrzykowski, Ł., submitted to A&A (2018)

Hamanowicz, A., et al., in preparation (2018)

Hodgkin, S. T., Wyrzykowski, L., Blagorodnova, N., Koposov, S., *Philosophical Transactions of the Royal Society of London Series A* **371**, 20120239 (2013)

Klencki, J., Wyrzykowski, Ł., Kostrzewa-Rutkowska, Z., Udalski, A., *Acta Astron.* **66**, 15 (2016)

Kozłowski, S., et al., *Acta Astron.* **63**, 1 (2013)

Kruszyńska, K., et al., in preparation (2018)

Tadhunter, C., et al., *Nature Astronomy* **1**, 0061 (2017)

Trakhenbrot, B., et al., submitted to Nature Astronomy (2018)

Udalski, A., Szymański, M. K., Szymański, G., *Acta Astron.* **65**, 1 (2015)

Wyrzykowski, Ł., Hodgkin, S., in E. Griffin, R. Hanisch, R. Seaman (eds.) New Horizons in Time Domain Astronomy, *IAU Symposium*, volume 285, 425–428 (2012)

Wyrzykowski, Ł., Hodgkin, S. T., Blagorodnova, N., Belokurov, V., in S. Feltzing, G. Zhao, N. A. Walton, P. Whitelock (eds.) Setting the scene for Gaia and LAMOST, *IAU Symposium*, volume 298, 446–446 (2014a)

Wyrzykowski, Ł., et al., *Acta Astron.* **64**, 197 (2014b)

Wyrzykowski, Ł., et al., in preparation (2018)