Gravitational Microlensing Events from the First Year of the Northern Galactic Plane Survey by the Zwicky Transient Facility

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The Zwicky Transient Facility (ZTF) (Bellm et al. 2019; Graham et al. 2019; Masci et al. 2019) is currently surveying the entire northern sky, including dense Galactic plane fields. Here, we present preliminary results of the search for gravitational microlensing events in the ZTF data collected from the beginning of the survey (2018 March 20) through 2019 June 30.

Searches for gravitational microlensing events have been traditionally confined to the Galactic bulge, where the probability of microlensing (and the event rate) is the highest. However, in recent years a number of bright
Gravitational microlensing events were discovered outside the Galactic bulge. For example, Nucita et al. (2018) found a super-Earth-mass planet in a high-magnification event TCP J05074264+2447555 detected toward the Galactic anticenter ($l \approx 179^\circ$). This was the first event with two images generated by gravitational microlensing resolved with the interferometric observations (Dong et al. 2019). Wyrzykowski et al. (2019) was able to measure all orbital parameters of the binary lens in the spectacular event Gaia16aye ($l \approx 65^\circ$).

Gravitational microlensing enables one to find many types of "dark objects," including neutron stars, single and binary black holes. While photometric observations alone are usually insufficient to determine masses of lensing objects, the combination of ground-based photometry and precise astrometric Gaia satellite observations will enable achieving that goal (e.g., Lu et al. 2016). Microlensing events located in the Galactic disk have, on average, larger angular Einstein radii than Galactic bulge events (Sajadian & Poleski 2019), so the astrometric signal is stronger. Gaia performance in the dense Galactic bulge fields is suboptimal so it is important to identify as many microlensing events as possible in the less crowded Galactic disk fields.

ZTF conducts the Galactic Plane Survey with nightly observations of all visible fields in the region $|b| < 7^\circ$, $\delta > -31^\circ$ in $g$ and $r$ bands. Additionally, Galactic plane fields are observed as part of ZTF collaboration and Caltech surveys.

We plan to carry out a comprehensive analysis of microlensing events in the ZTF footprint (including the measurements of the microlensing optical depth and event rate) in the future. Here, we present the first discoveries based on the first ~15 months of the survey that demonstrate that the current observing strategy enables the identification and characterization of microlensing events in the Galactic disk fields.

Our methodology is similar to that used in our previous works (Mróz et al. 2017, 2019). We analyzed $r$-band light curves of objects associated with ZTF alerts in 408 fields at low Galactic latitudes ($|b| \leq 20^\circ$); we required at least five alert detections (meaning that the object was detected on a difference image produced by the Zackay et al. 2016 algorithm). Then, we searched for objects with at least three consecutive data points that are at least $3\sigma_{\text{base}}$ brighter than the baseline flux $F_{\text{base}}$, where $F_{\text{base}}$ and $\sigma_{\text{base}}$ were calculated using data points outside a 160 days window centered on the event. We also
fitted the microlensing point-source point-lens model to the light curves of all candidate objects. We selected candidate events that (1) do not exhibit any variability outside the window centered on the event, and (2) can be well-described by a microlensing point-lens point-source model. The light curves of selected candidates were additionally visually vetted by a human expert. The final models are based on simultaneous modeling of *g*- and *r*-band light curves.

We found 30 likely events which are listed in Table 1. The full table, including best-fitting model parameters, is available online. Although the current sample is relatively small, the properties of detected events are different from those of Galactic bulge events. All detected events have relatively long Einstein timescales ($30 \lesssim t_E \lesssim 200$ days) whereas typical timescales of bulge events are shorter ($t_E \sim 20$ days) (e.g., Mróz et al. 2017). This may be partly explained by selection biases, but we have demonstrated (Mróz et al. 2019) that nightly observations are sufficient to detect events with timescales as short as a few days. From the theoretical point of view (e.g., Sajadian & Poleski 2019), it is expected that, on average, Galactic plane events should be longer than those in the bulge direction because the source and the lens, both in the Galactic disk, are moving in a similar direction.

### Table 1. Gravitational Microlensing Events in the ZTF DR2 Data

| Event          | R.A.     | Decl.     | *l*     | *b*     | Remarks     |
|----------------|----------|-----------|---------|---------|-------------|
| ZTF18aatnfdf   | 286.633211 | 32.248996 | 63.592037 | 11.173057 |             |
| ZTF18aazdbym   | 290.784286 | 7.810517  | 43.509003 | −3.416870 |             |
| ZTF18aaztjyd   | 326.173116 | 59.377872 | 101.101575 | 4.669597  |             |
| ZTF18aazwhtw   | 339.955528 | 51.647223 | 103.116644 | −6.088552 |             |
| ZTF18abaqxrt   | 290.617225 | 1.706486  | 38.010990 | −6.113752 |             |
| ZTF18abhxjmj   | 284.029167 | 13.152260 | 45.192580 | 4.937164  |             |
| ZTF18ablrbkj   | 271.850400 | −10.314477 | 18.695441 | 4.908538  |             |
| ZTF18ablrdcc   | 271.439120 | −12.014556 | 17.006029 | 4.441709  | Gaia18ch   |
| ZTF18ablruzq   | 284.338291 | 11.433438 | 43.790788 | 3.892060  | binary     |
| ZTF18abmoxlq   | 285.984027 | −13.929477 | 21.832965 | −9.024192 |             |
For four of the detected events, we were able to measure microlens parallax. ZTF18abaqawft is particularly interesting because the source is bright ($r \approx 14.7$) and so the *Gaia* satellite have likely measured the astrometric

| Event          | RA     | Dec    | $m_V$  | $\xi$   | Notes        |
|----------------|--------|--------|--------|---------|--------------|
| ZTF18abaqawft  | 287.113964 | 1.531903 | 36.239259 | -3.084660 | binary       |
| ZTF18abaqazwft | 285.134471 | 30.511120 | 61.434070 | 11.599466 | binary?      |
| ZTF18abqbeqv   | 279.578723 | 7.837854  | 38.448164 | 6.467501  |              |
| ZTF18absrqlr   | 307.149376 | 22.830478 | 64.600302 | -9.235573 |              |
| ZTF18abtnvsg   | 291.019150 | 20.478976 | 54.790638 | 2.361105  |              |
| ZTF18acskgwu   | 76.632447  | 8.425664  | 192.546959 | -18.799234 | binary       |
| ZTF19aabbuqn   | 48.694244  | 62.343390 | 138.738918 | 3.955177  |              |
| ZTF19aaekacq   | 279.404621 | 11.200516 | 41.407932 | 8.116296  |              |
| ZTF19aainwvb   | 55.197569  | 57.955805 | 143.884446 | 2.147052  | Gaia19bj     |
| ZTF19aamlgyh   | 289.114418 | 26.653532 | 59.467936 | 6.770307  | Gaia19as     |
| ZTF19aamrjmu   | 280.734529 | 32.873054 | 62.121495 | 15.974788 |              |
| ZTF19aaonska   | 273.900566 | -2.256985 | 26.802123 | 6.922664  | Gaia19av     |
| ZTF19aaprng    | 274.913476 | 0.590991  | 29.819420 | 7.338351  |              |
| ZTF19aatudn    | 290.663294 | 19.550373 | 53.813242 | 2.218551  | Gaia19bz     |
| ZTF19aatwaux   | 258.208411 | -27.182057 | 357.476262 | 7.002211  |              |
| ZTF19aavisrq    | 297.706148 | 34.637344 | 70.054958 | 4.102724  | Gaia19da     |
| ZTF19aavndrc   | 281.836951 | -4.338099 | 28.604991 | -1.068892 |              |
| ZTF19aavnqrt   | 309.034132 | 32.720880 | 73.669581 | -4.807238 |              |
| ZTF19aaxsdqz   | 283.497170 | -1.152267 | 32.197043 | -1.092856 |              |

**Notes.** Equatorial coordinates are given for the epoch J2000.

*Possible microlensing event.*
microlensing signal. We also detected five likely binary microlensing events (ZTF18abrlruzq, ZTF18abqawpf, ZTF18abqazwf, ZTF18acskgwu, ZTF19aatudnj). Preliminary models indicate that these events were caused by stellar binaries.

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Footnotes

8  [http://www.astro.caltech.edu/~pmroz/microlensing_ZTF.pdf](http://www.astro.caltech.edu/~pmroz/microlensing_ZTF.pdf)

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