Microlensing in the Era of All Sky Surveys

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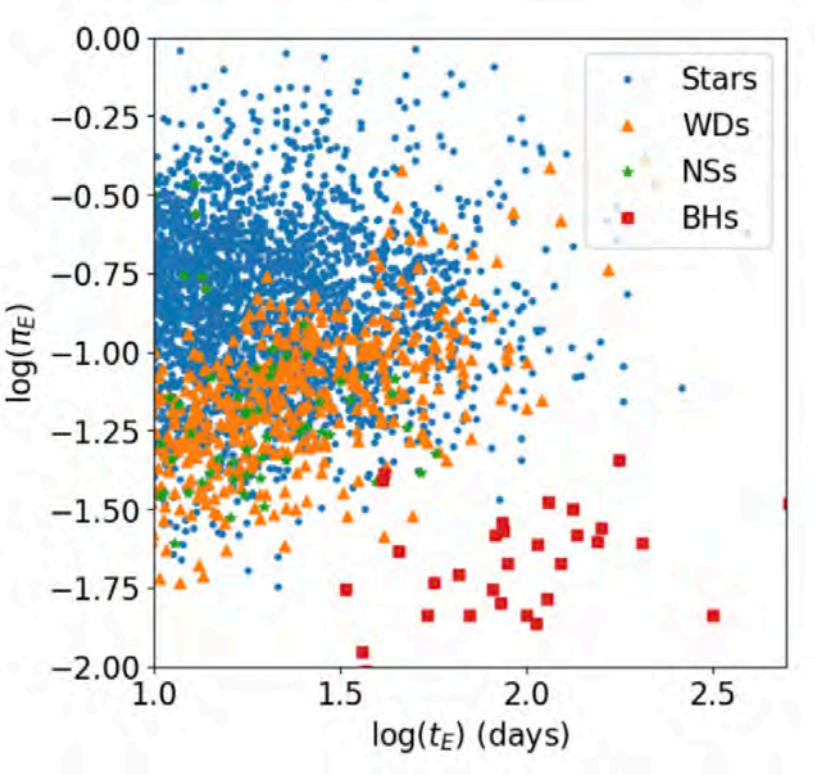
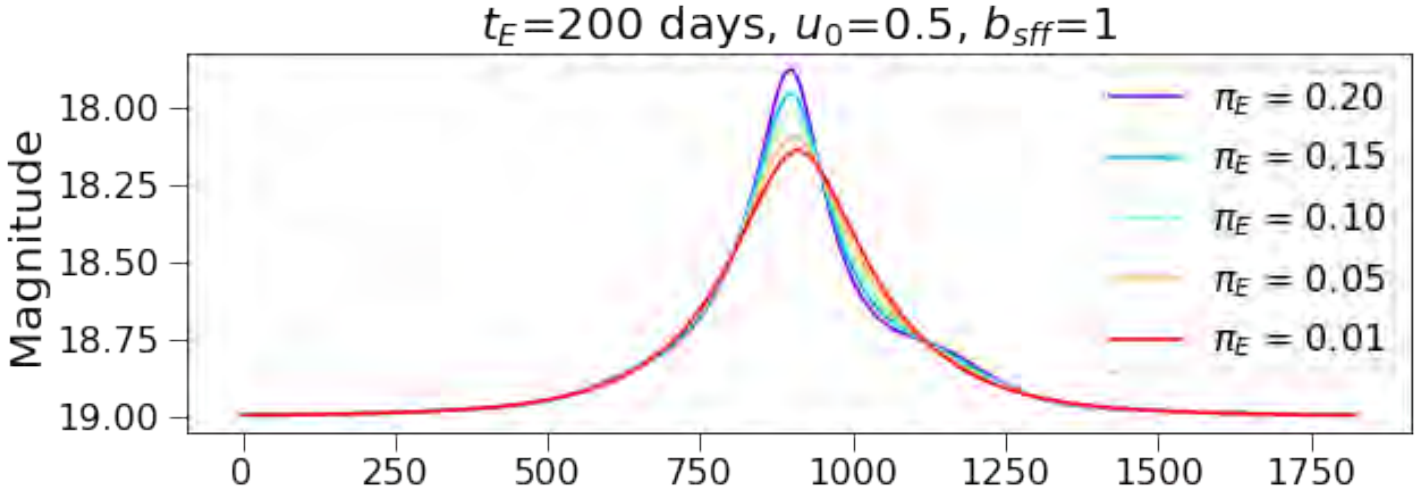
Microlensing 26 – 1-31-24

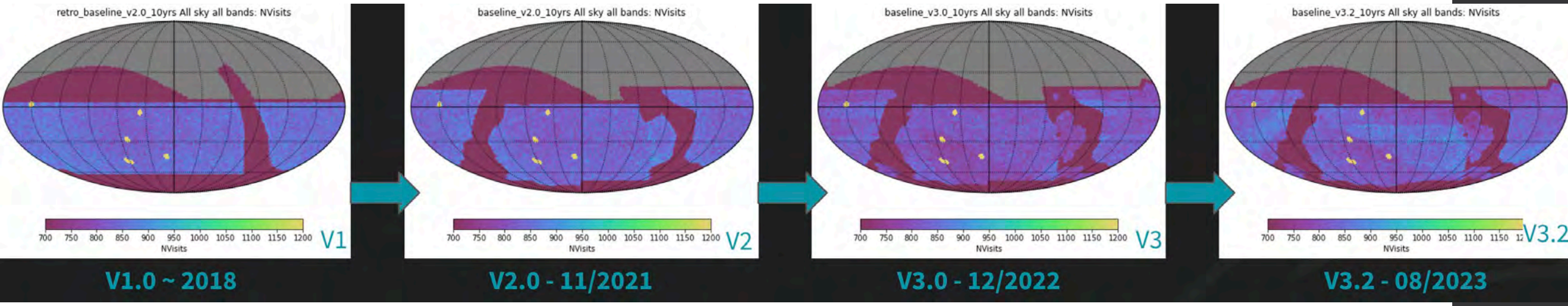
Measurable quantities

- Einstein crossing time - t_E - duration $t_E \propto \frac{\sqrt{M\,\pi rel}}{\mu rel}$
- Microlensing parallax (π_E):
  - Over the course of the year – observing microlensing event from different angles can lead to bumps and asymmetries in the lightcurve $\pi_E \propto \frac{\sqrt{\pi rel}}{\sqrt{M}}$
- Identify black holes in π_E vs t_E

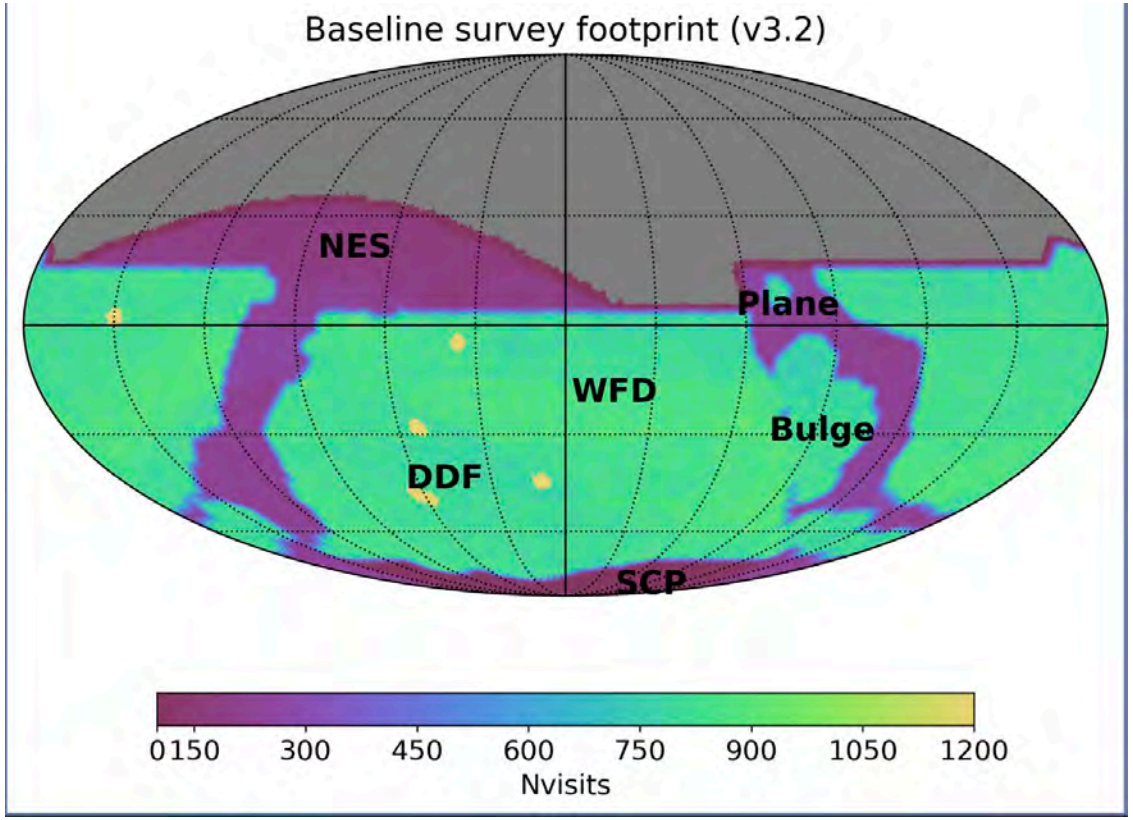




Need large photometric survey to find black holes through microlensing

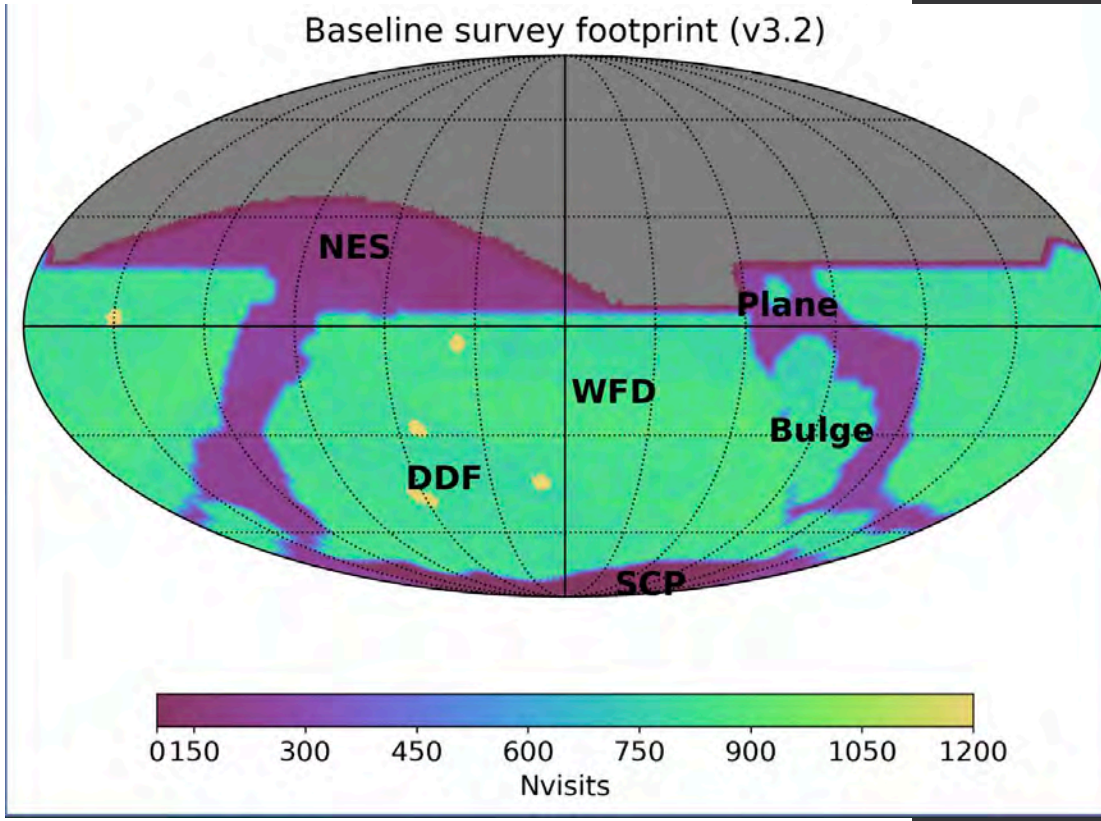


Rubin Observatory Community Driven Survey Optimization Process



Quantifying Impact of Rubin Survey Strategy on Microlensing

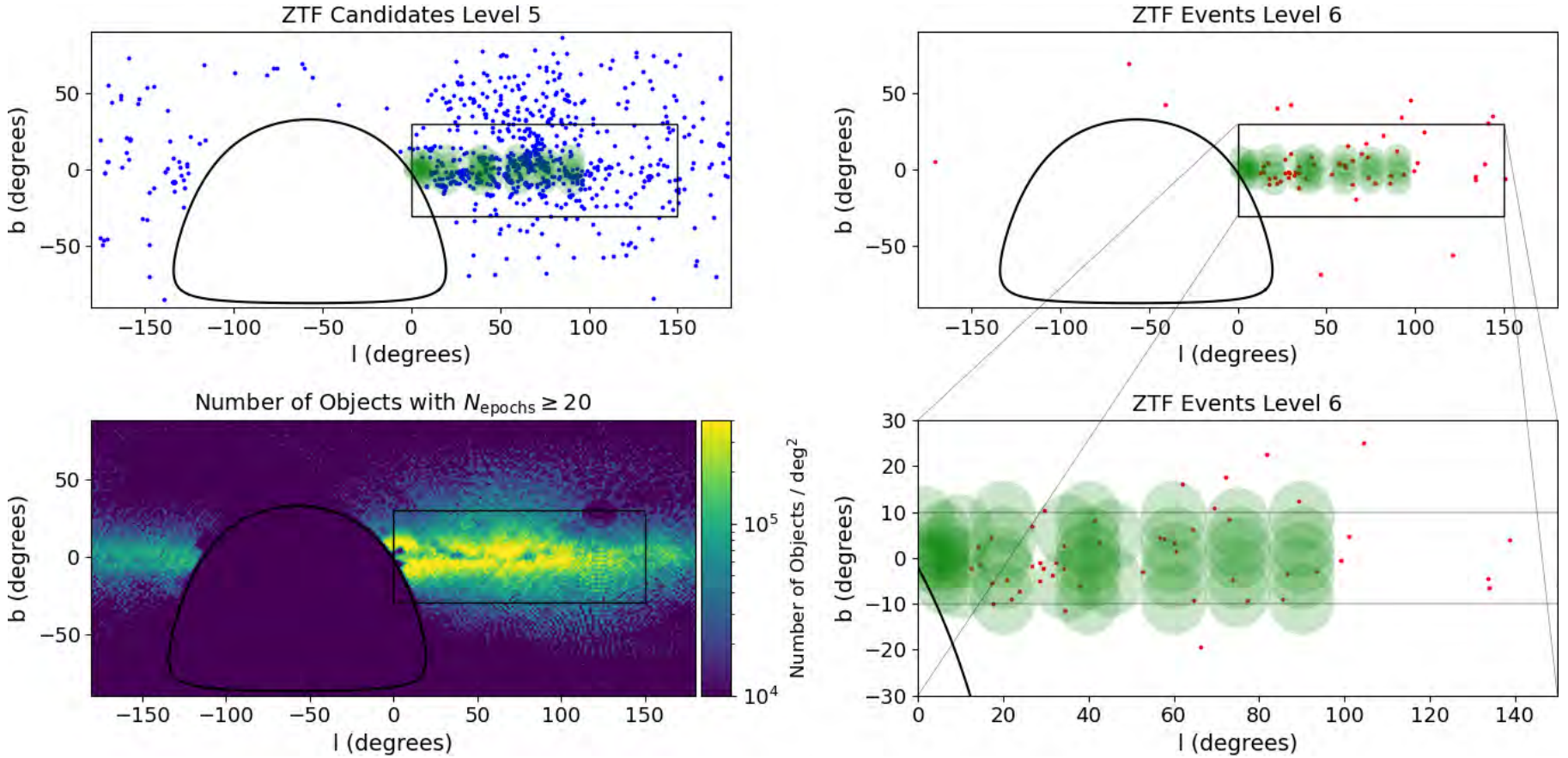
- Focusing on high stellar density areas (e.g. Galactic plane and bulge) have the most significant impact on microlensing detection and characterization
  - Including them improves BH event detection by ~50%
- Rubin will measure BH population vs place in galaxy
  - Taking observations throughout the plane optimizes ability to discover events throughout the plane with a 10-20% drop in characterization efficiency
- Rolling in the bulge and plane should be done carefully to allow for microlensing parameter characterization
  - Roman or less severe rolling (optimize to fill in gaps)



Abrams et al., in review

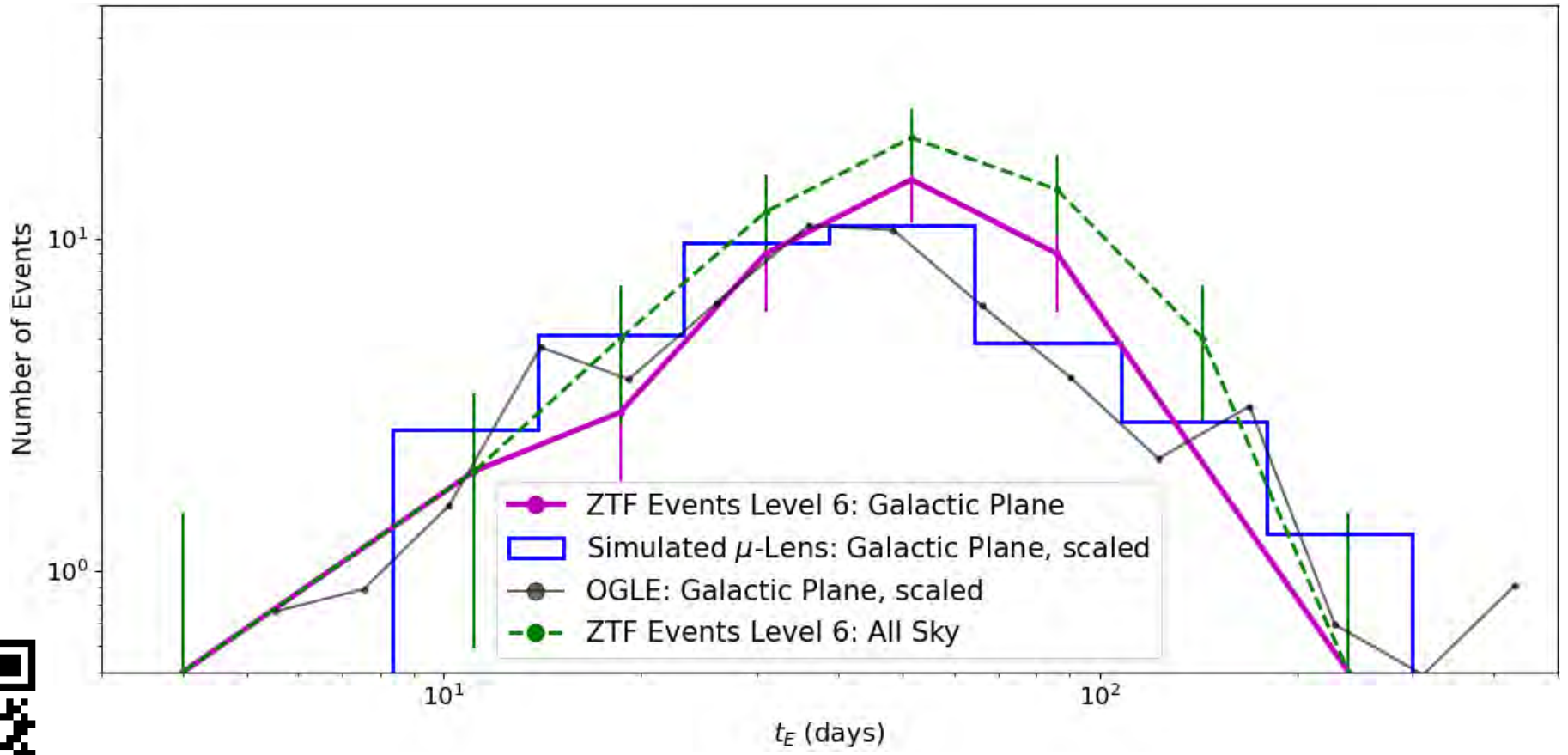
Testing methods with ZTF data
First three years of ZTF: 60 Events (19 outside of galactic plane)

- 28 events overlapped with Rodriguez et al. 2022.



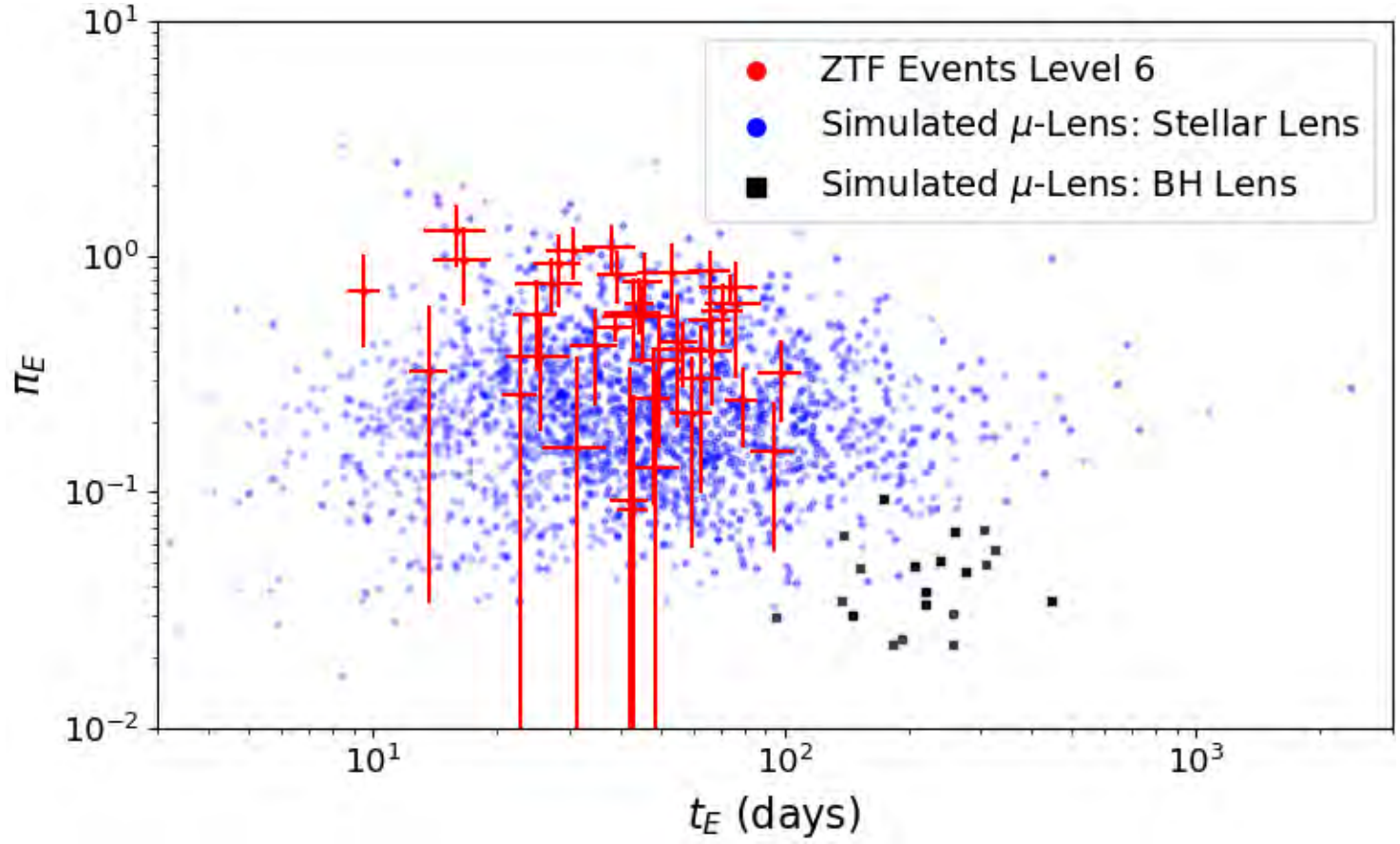
Medford & Abrams et al. 2023

Simulated vs OGLE vs ZTF t_E distributions in good agreement



Medford & Abrams et al. 2023

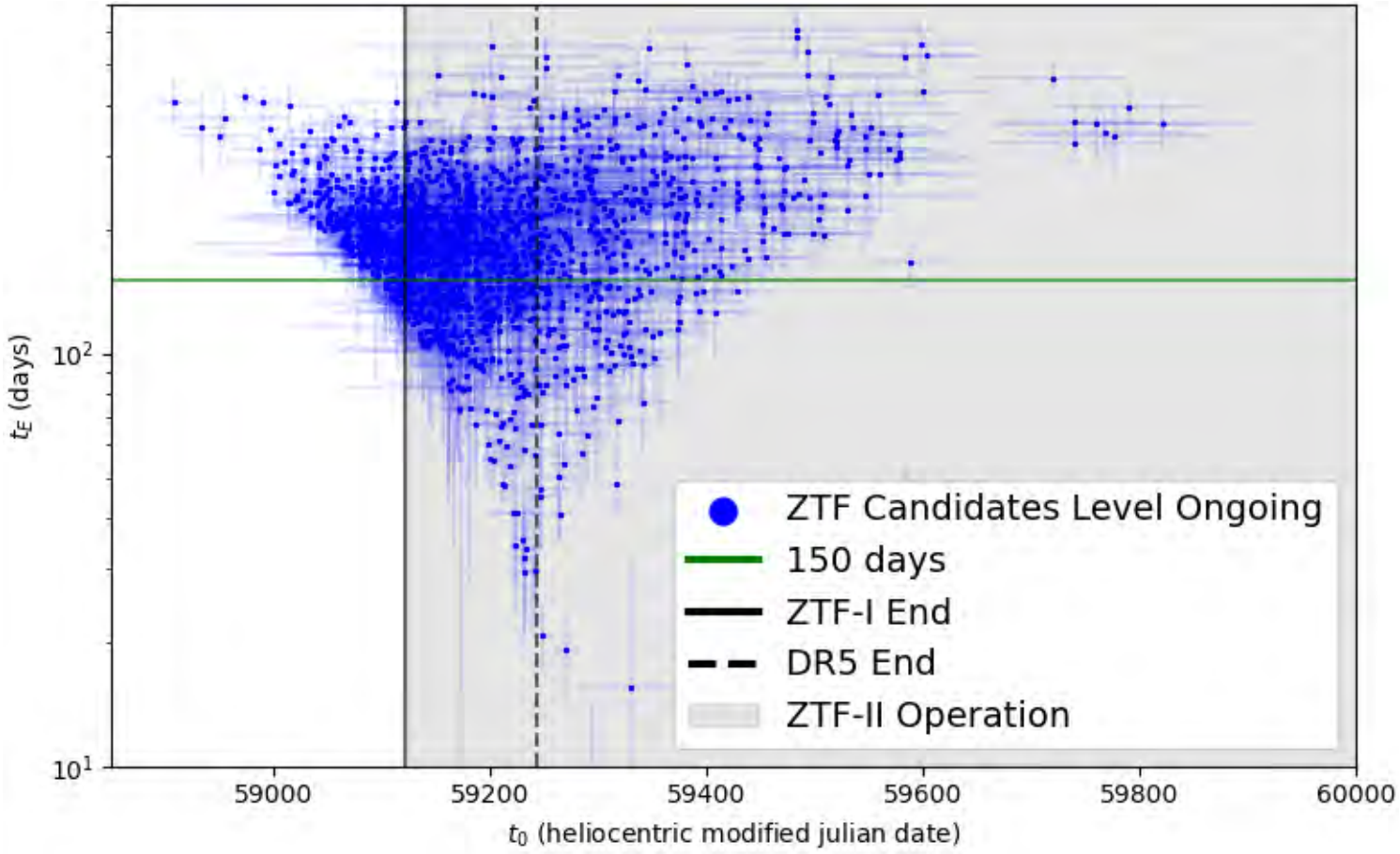
No likely black hole candidates in first 3 years of data



Medford & Abrams et al. 2023

802 Ongoing Candidates with t_E > 150 days

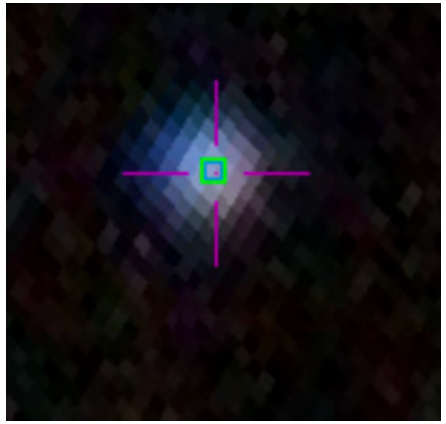
- No completed black hole candidates
- If same rate of real microlensing events as complete events at this stage → a few candidate black holes
- In 5 years of data found 124 events with 12 ≳ 150 days (Zhai et al. 2023)

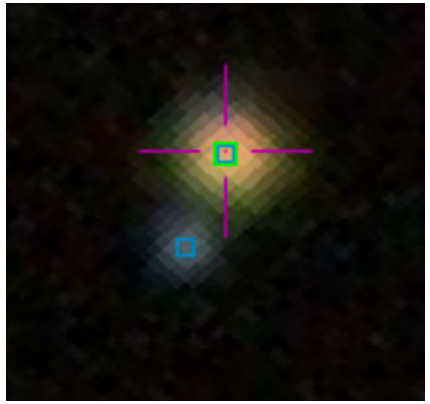


Medford & Abrams et al. 2023

Investigating Nature of Out of Plane Objects

- 5 events have Gaia parallaxes with significance > 3σ
  - 0.7-4 kpc away
- 3 events have SDSS redshifts z ~ 1, 2 of which are classified as quasars (AAVSO and Million Quasar Catalogs), but also have Gaia parallaxes
- 2 events have radio signals < 1” away (NVSS)
- In Progress: Follow-up data to verify Galactic origin of event



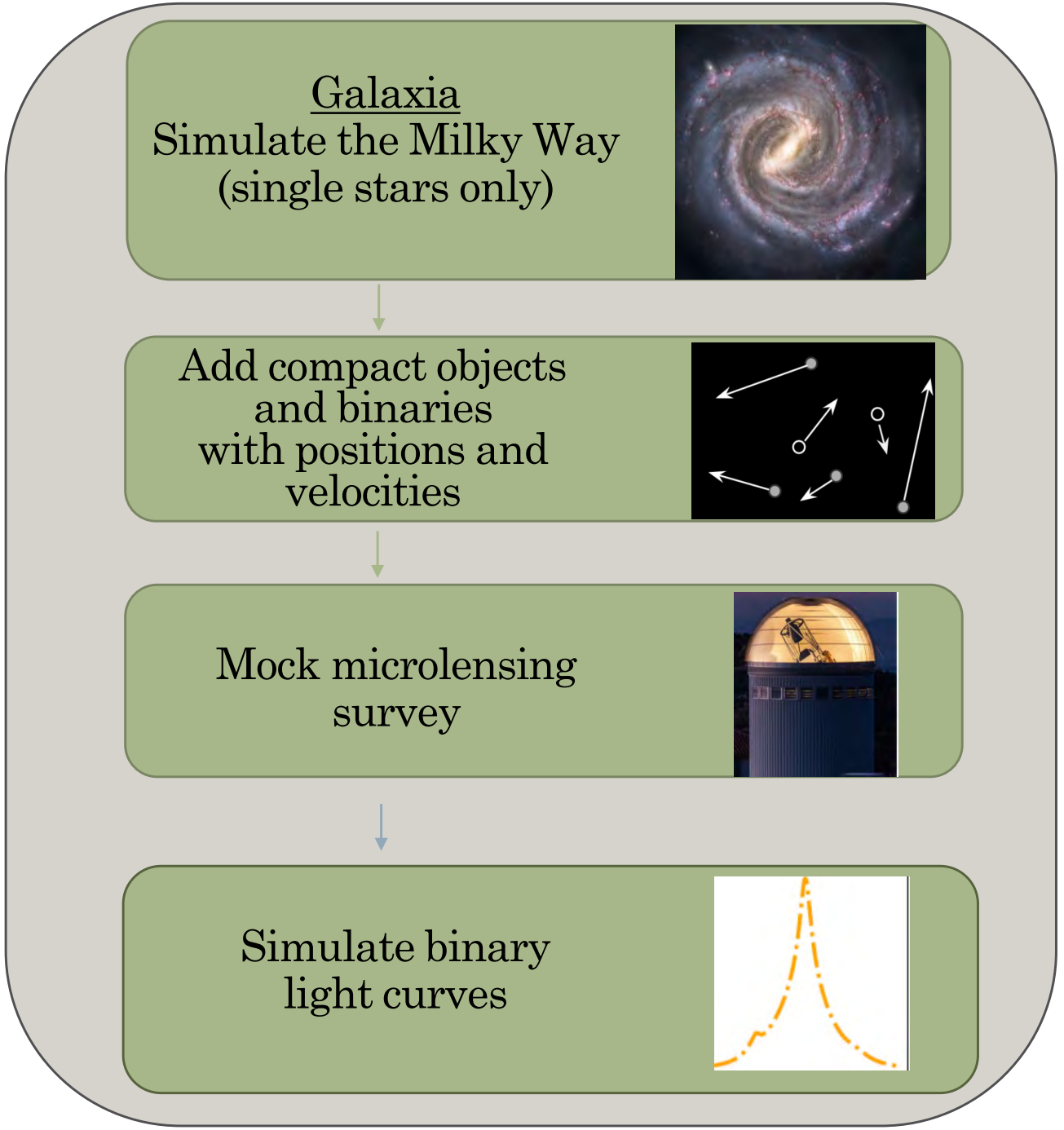


Predicting and Modeling Galactic Black Hole and Binary Populations with PopSyCLE Simulation

https://github.com/jluastro/PopSyCLE

PopSyCLE

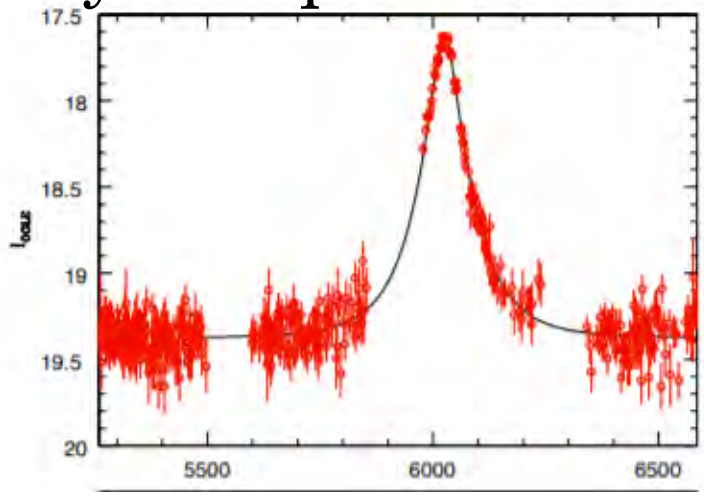
- Population Synthesis code
- Useful beyond microlensing!



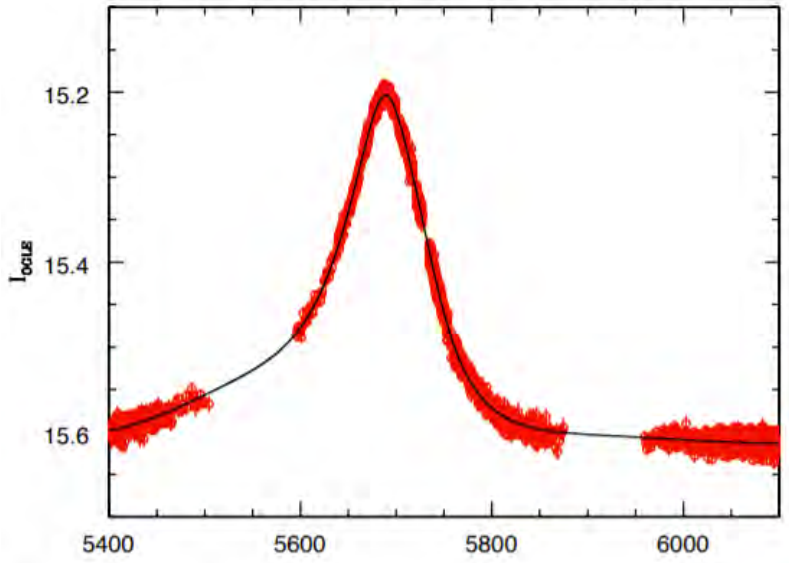
Galaxia – Sharma et al. 2011;
SPISEA – Hosek et al. 2020;
PopSyCLE – Lam et al. 2020

https://github.com/jluastro/PopSyCLE

We want to know how often black holes are in binaries and understand when they make a measurable binary signal or when they masquerade as single lenses



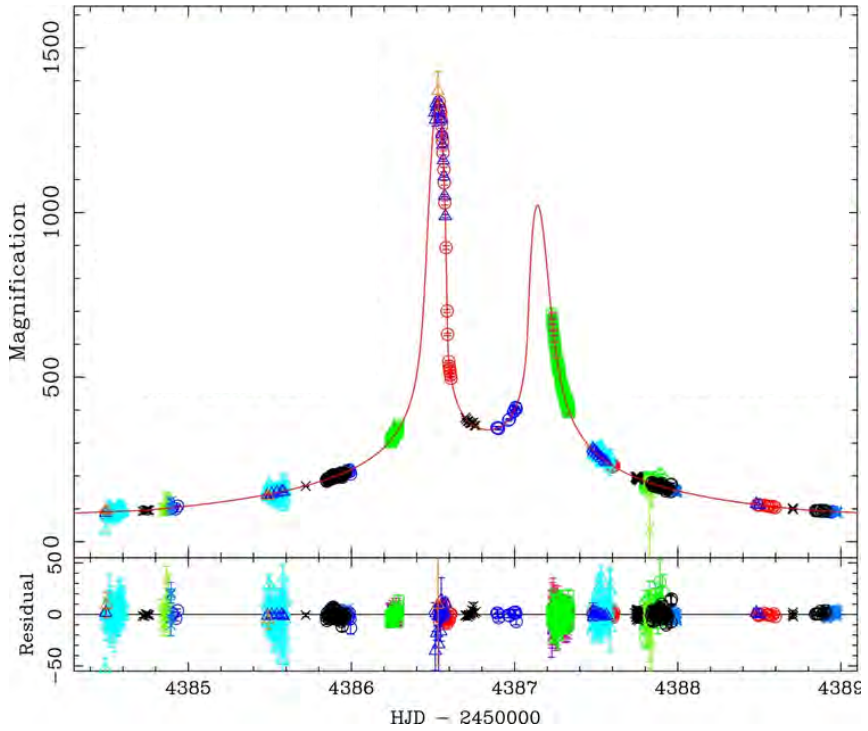
Single lens



Source: Lu et al. 2016

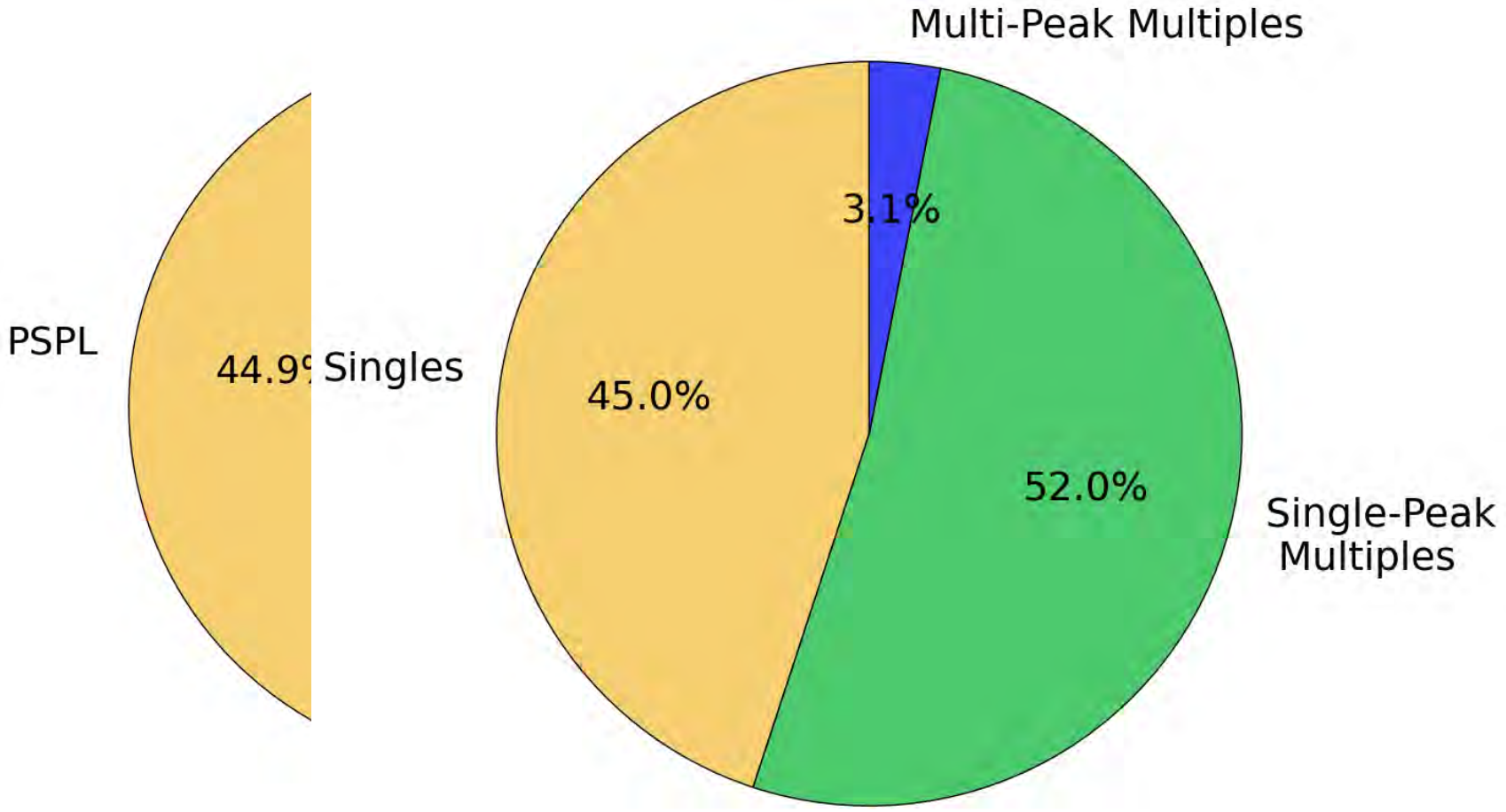
Ambiguous Binary lens

Obvious binary



Source: Miyake et al. 2012

More than half of stellar and compact object microlensing events have at least one binary …~52% appear as singles

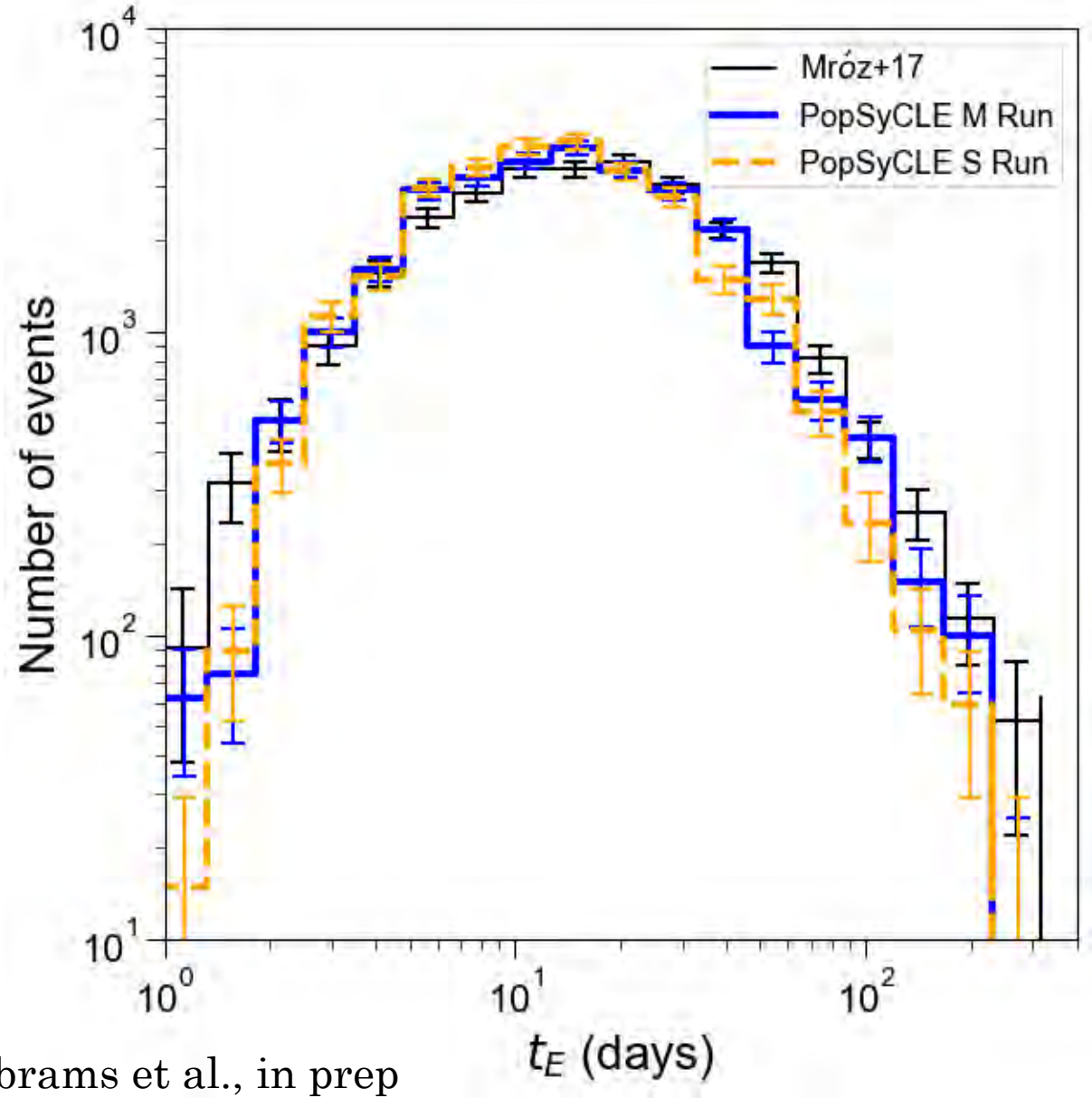


Abrams et al., in prep

Brings t_E distribution into agreement with data

- Mean t_E averaged across 18 fields:
  - OGLE: 25.6±3.3 days
  - Singles only: 18.7±1.2 days
  - Singles + single peaked multiples: 25.6±1.4 days

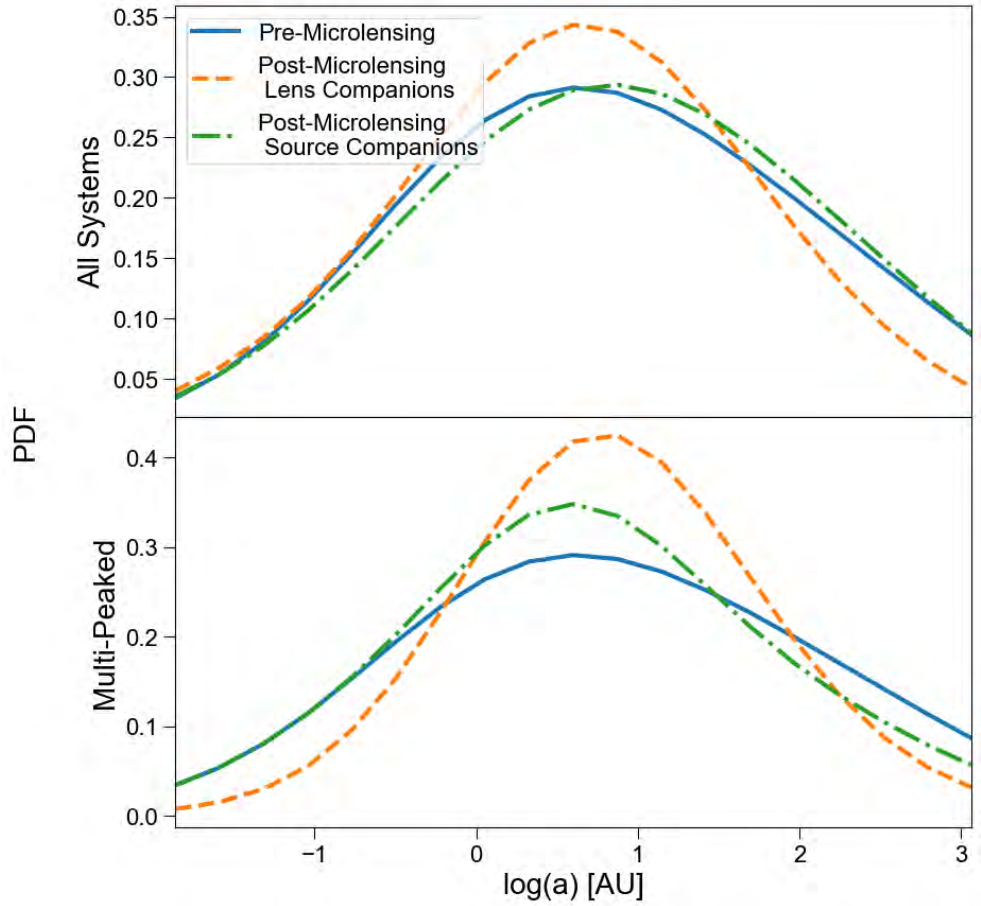
- S Run – Model with only singles
- M Run – Model with multiples and singles

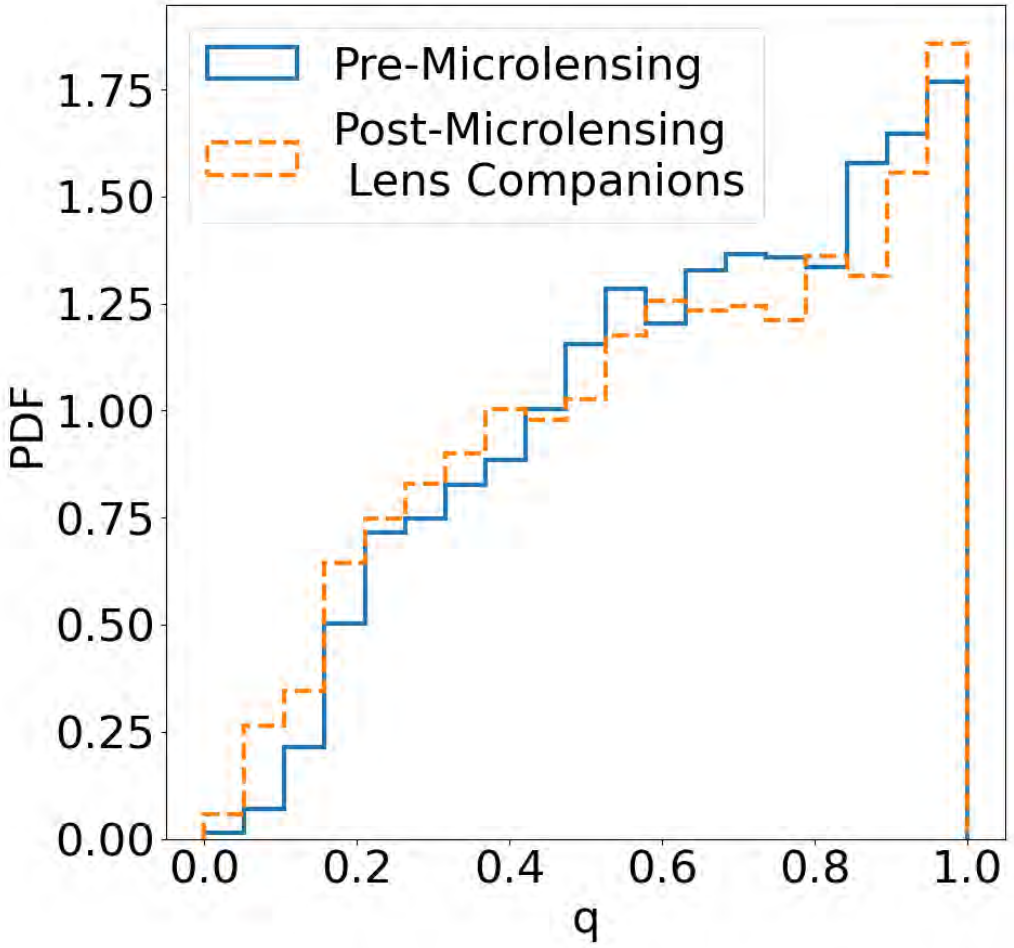


Abrams et al., in prep

Mróz et al. 2017
Mróz et al. 2019

Binary Parameter Bias with Microlensing





Abrams et al., in prep

Summary

- Inclusion of high stellar density areas in Rubin such as Galactic bulge and plane increase microlensing discovery and characterizations by ~50% for black holes
- We discovered 60 high-quality microlensing events in the 3 yrs of ZTF data including 19 outside the Galactic plane
- We find that > 50% of our simulated events with PopSyCLE include a binary lens or source system creating both false positives and false negatives when identifying BHs
- Critical for microlensing surveys to include binarity in predictions and modeling

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Rubin Paper: Abrams et al., in review

ZTF Paper: Medford & Abrams et al. 2023