# Microlensing Discovery and Characterization Efficiency in the Vera C. Rubin Legacy Survey of Space and Time

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Rubin PCW 2023

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### Gravitational Microlensing Intro



#### Microlensing by its nature occurs in crowded fields





Lam et al. 2022

# MicrolensingMetric in MAF

Discovery	Characterization
• At least two points on the rising portion of the lightcurve	• Fisher Matrix Metric - quantifying how well we can measure the event parameters
	• Npts Metric - # of points within $2t_E$
<ul> <li>Density of events of</li> </ul>	distributed as $(N_{stars})^2$

Baseline mag mean from TRILEGAL:
u: 25.2, g: 25.0, r: 24.5, i: 23.4, z: 22.8, y: 22.5

# In cadence, footprint has strongest impact on microlensing

- Retro footprint with minimal inclusion of Galactic bulge and plane >60% worse than baseline v2.0 Fraction w/ sigma\_tE/tE < 0.1 tE 200\_500 day Fraction w/ sigma\_tE/tE < 0.1 tE 20\_30 day Fraction w/ at least 10 points tE 200\_500 day Fraction w/ at least 10 points tE 200\_500 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 20\_30 day
- Baseline v2.0-v2.2 focused on Galactic bulge increases number discovered and characterized
- Baseline v3.0 includes Galactic plane – discover throughout the Galactic plane. Decreases characterizability by 15-20%

Fraction w/ sigma tE/tE < 0.1 tE 200 500 day Fraction w/ sigma tE/tE < 0.1 tE 30 60 day Fraction w/ sigma tE/tE < 0.1 tE 20 30 day Fraction w/ sigma tE/tE < 0.1 tE 10 20 day Fraction w/ at least 10 points tE 30 60 day Fraction w/ at least 10 points tE 20 30 day Fraction w/ at least 10 points tE 10 20 day Total detected tE 500 1000 day Total detected tE 200 500 day Total detected tE 100 200 day Total detected tE 60 90 day Total detected tE 30 60 day Total detected tE 20\_30 day Total detected tE 10 20 day Total detected tE 5 10 day Total detected tE 1\_5 day



## Parallax Characterization with Fisher Information Matrix

- Microlensing parallax asymmetries or bumps in lightcurve from variation of line of sight
  - Differences in lens and source parallax
- Random  $\mathbf{\pi}_{E}(0, 1)$  in a random direction
- Representative bulge patch (RA = 263.89, Dec = -27.16) and disk patch (RA = 288.34, Dec = 9.66)
- 100,000 events each using BAGLE (Bayesian Analysis of Gravitational Lensing Events)

#### **Baseline 2.0 Characterization**



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### All Sky Rolling Decreases characterizability in bulge by 5-10%



# Extreme rolling in bulge decreases characterizability in bulge by ~15%



# Next Steps

- End-to-end simulation to find estimate number and population of expected detected and characterized events
  - Including more realistic filter balance
- Working with pipeline team to maximize microlensing detection ability in crowded fields

# Summary

- Footprint makes the most significant impact on microlensing detection and characterization
- In baseline v3.0, 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)

#### Fisher Information Matrix

$$I_{i,j} = \sum_{k=1}^{N_{\text{data}}} \frac{1}{\sigma_F^2(t_k)} \left(\frac{\partial F_{\text{model}}(t_k)}{\partial p_i}\right) \left(\frac{\partial F_{\text{model}}(t_k)}{\partial p_j}\right)$$

## **Optimizing Galactic Plane Inclusion**

- Including Galactic plane leverages Rubin's unique capability
- Including regions with priority < 0.6 leads to a drop > 10% characterization efficiency
- Filter balance still to be optimized

Fraction w/ sigma tE/tE < 0.1 tE 200 500 day Fraction w/ sigma tE/tE < 0.1 tE 30 60 day Fraction w/ sigma tE/tE < 0.1 tE 20 30 day Fraction w/ sigma tE/tE < 0.1 tE 10 20 day Fraction w/ at least 10 points tE 200\_500 day Fraction w/ at least 10 points tE 30 60 day Fraction w/ at least 10 points tE 20 30 day Fraction w/ at least 10 points tE 10\_20 day Total detected tE 500\_1000 day Total detected tE 200 500 day Total detected tE 100 200 day Total detected tE 60 90 day Total detected tE 30\_60 day Total detected tE 20 30 day Total detected tE 10 20 day Total detected tE 5 10 day Total detected tE 1\_5 day



# Triplet observations decrease most microlensing efficiency

• Most microlensing events change on scales >> 1 night, so spreading out observations increases efficiency



## Rolling must be done carefully

- Current rolling strategies decreases discoverability and characterizability for most microlensing events (besides <5-10 days events)
- Rolling to synergize with Roman or less severe rolling (optimize to fill in gaps)

Fraction w/ sigma\_tE/tE < 0.1 tE 200\_500 day Fraction w/ sigma tE/tE < 0.1 tE 30 60 day Fraction w/ sigma tE/tE < 0.1 tE 20 30 day Fraction w/ sigma tE/tE < 0.1 tE 10 20 day Fraction w/ at least 10 points tE 200 500 day Fraction w/ at least 10 points tE 30 60 day Fraction w/ at least 10 points tE 20\_30 day Fraction w/ at least 10 points tE 10\_20 day Total detected tE 500\_1000 day Total detected tE 200 500 day Total detected tE 100 200 day Total detected tE 60 90 day Total detected tE 30 60 day Total detected tE 20\_30 day Total detected tE 10 20 day Total detected tE 5 10 day Total detected tE 1 5 day



# Retro basline parallax characterization



