Hunting for Black Holes via Astrometric Microlensing (+ LS^4)

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Searching for Stellar Mass Black Holes

1) Photometric surveys
2) Candidate selection
3) Astrometric follow-up
4) Event fits

La Silla Schmidt Southern Survey (LS^4)

Telescope built from existing resources:

- ESO 1-meter Schmidt telescope
- Upgraded QUEST camera
- LBNL CCDs leftover from DES
- ~20 sq. deg. FOV
- Fixed multi-filter layout >

g	i
i	z

- SNR=5 photometry limits:

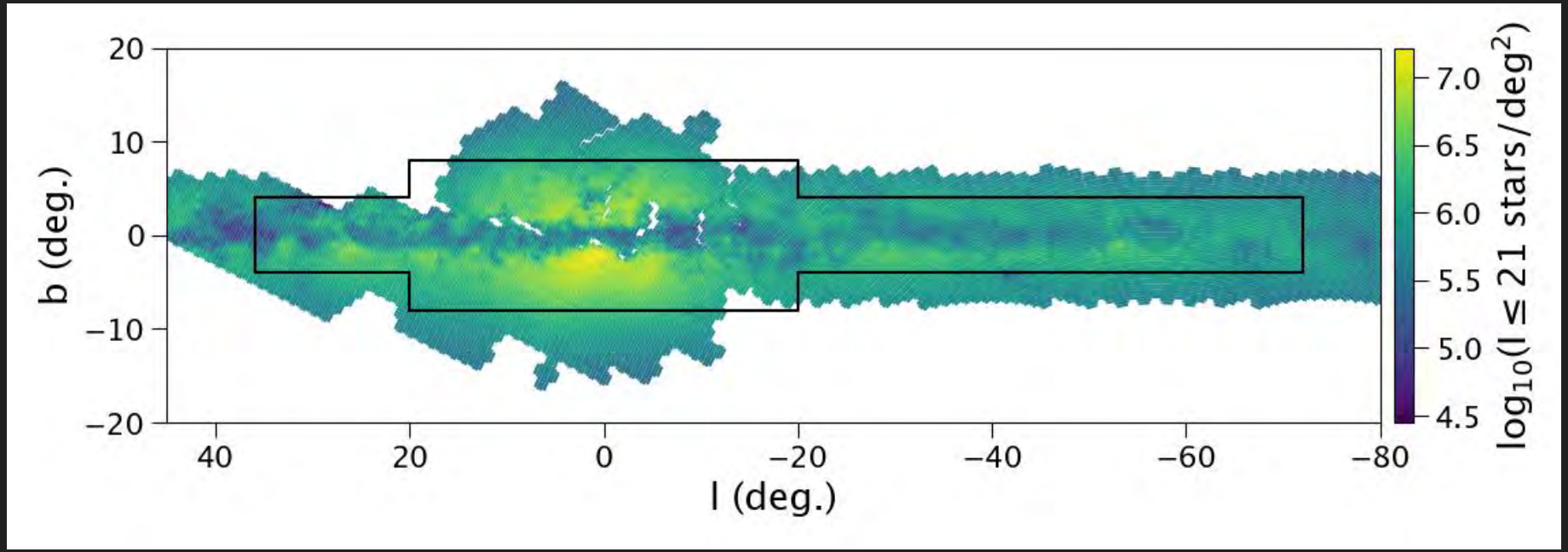
g: 22.0	i: 20.6	z: 19.1

- Planned 5-year survey, beginning Spring(?) 2024
- ~25% of time devoted to Galactic science

Image credit: ESO

LS^4 Galactic Survey Area

Tentative plan: nightly data in (all or a subset of) g, i, i, z bands in black outlined region

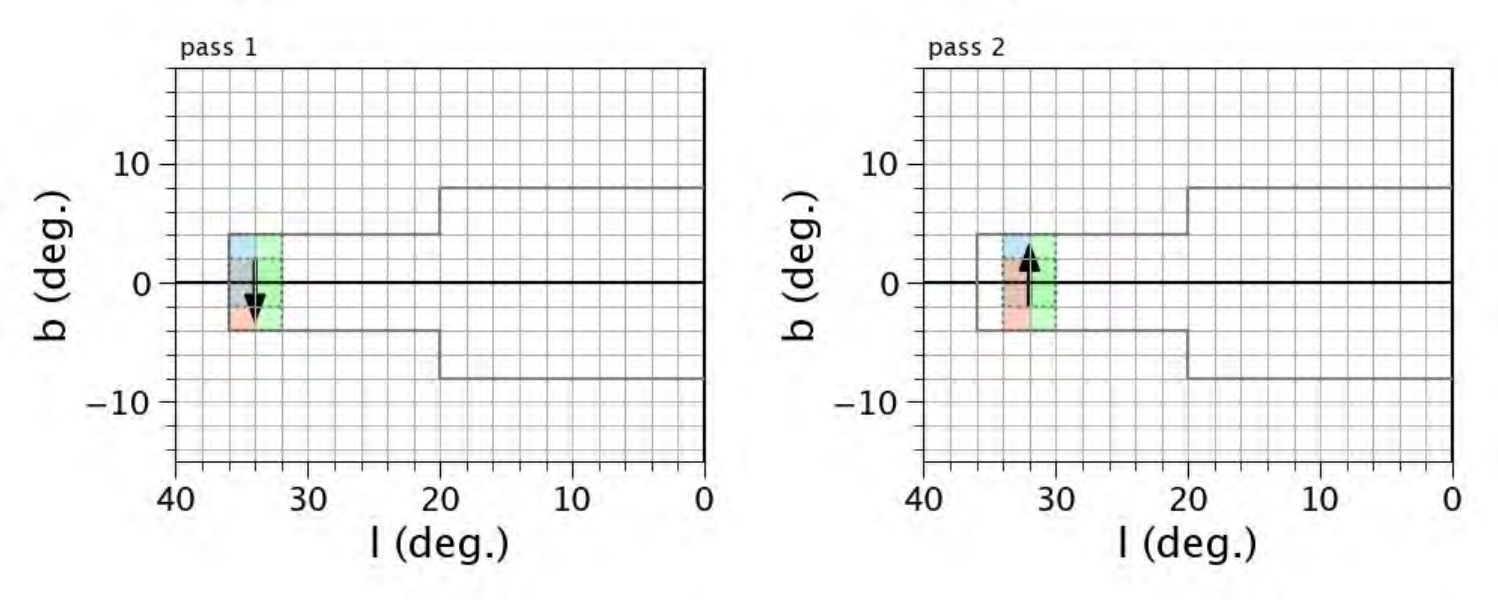


Star counts from Mróz et al, 2019+2020 (OGLE-IV)

LS^4 Galactic Survey Coverage vs. Cadence

g	i
i	z

Cadence: ~ 1 day



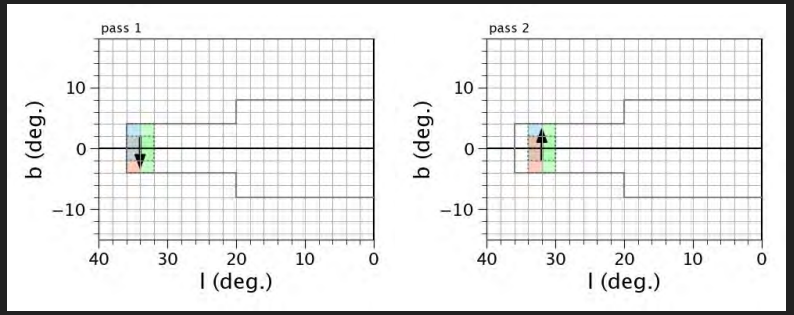
LS^4 Galactic Survey Coverage vs. Cadence

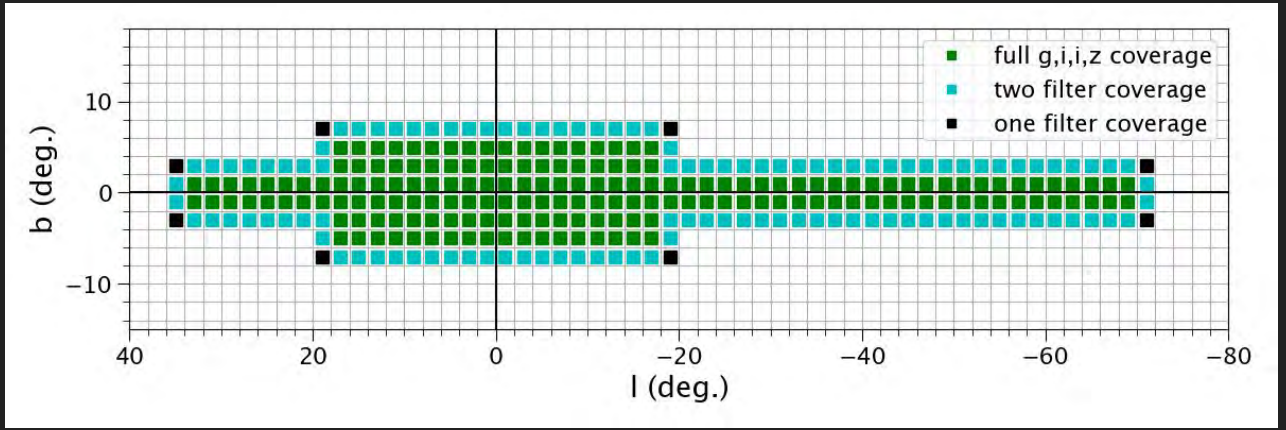
g	i
i	z

Cadence: ~ 1 day

Inner region with full 3-filter coverage (stackable i-band data)

Outer region with 1- to 2-filter coverage





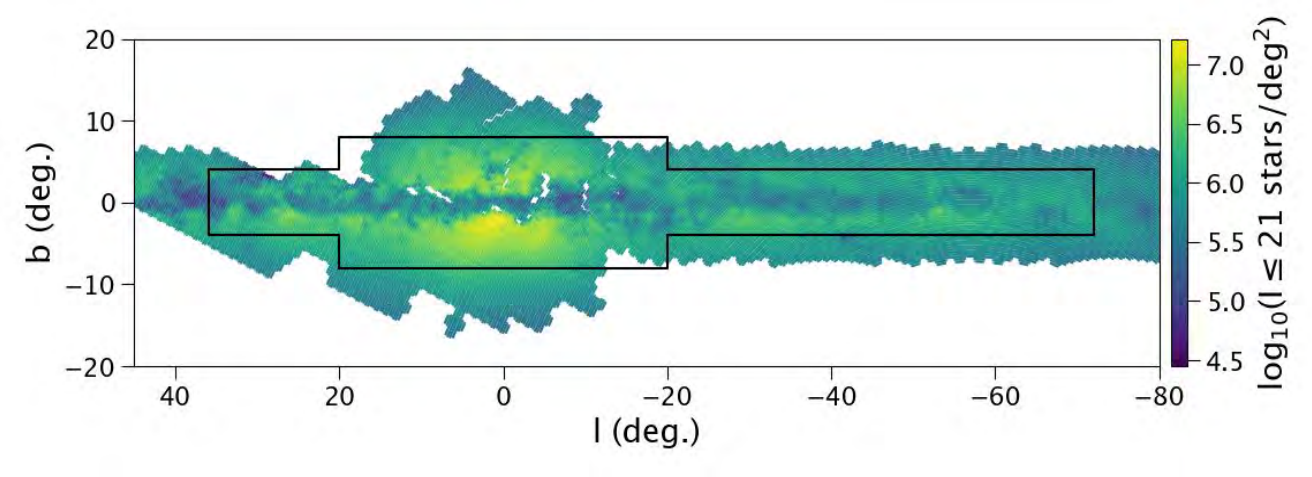
LS^4 Galactic Survey

Complementary to Rubin with higher cadence but not as deep

Complementary to ZTF with similar depth and cadence but in the Southern Hemisphere

Anticipate ~1,300 microlensing events in observed area during year 1

Survey data will be public



Star counts from Mróz et al, 2019+2020 (OGLE-IV)

Candidate Selection from Photometric Surveys

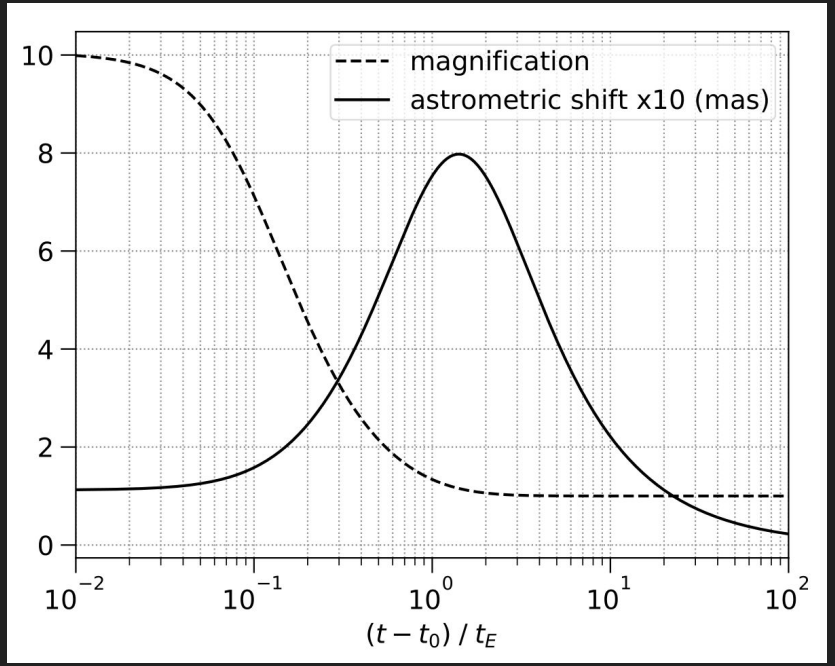
Good black hole candidates are those with:

- Long timescales
- Low microlensing parallax

See Anette Brecko’s poster for more on how we are streamlining this process!

Astrometric follow-up

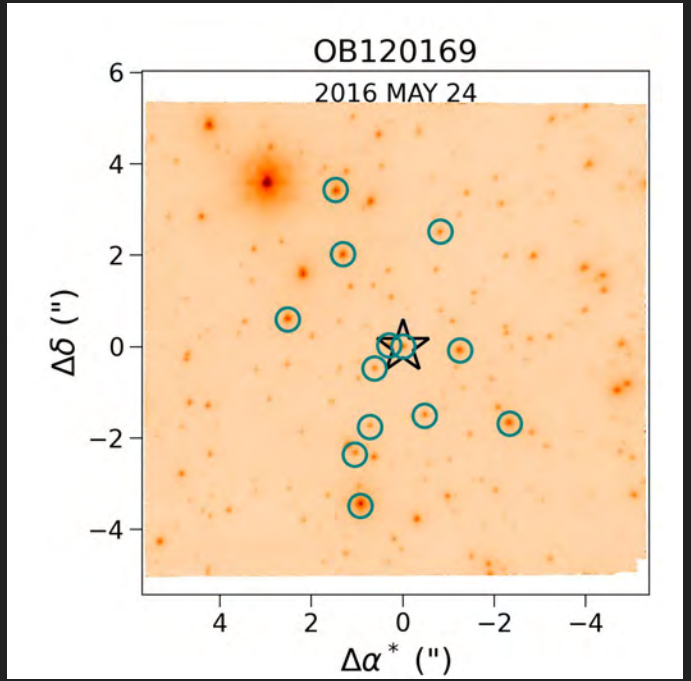
- Instruments like HST and Keck AO systems for diffraction limited imaging
- Need coverage of a few years in order to capture astrometric signal peak and baseline



Example photometric and astrometric signal (Lu et al., in prep)

Keck Astrometry

- Keck I and II 10-m telescope with laser guide star AO for NIR diffraction limited imaging
- Studying 4 events that peaked photometrically several years ago
- Most data using NIRC2, with some more recent epochs using OSIRIS
  - ~10 mas/pix plate scales
  - 10” (NIRC2) and 18” (OSIRIS) FOVs
- Re-reduction and analysis:
  - NIRC2 Non-linearity correction
  - OSIRIS Distortion Solution



Example NIRC2 image (Lu et al., in prep)

Event Fitting

BAGLE: Bayesian Analysis of Gravitational Lensing Events

Fitting and comparing results for a number of models:

- photometry and/or astrometry
- with and without certain data sets
- binary sources or lenses
- Gaussian processes

See our group members' posters about ongoing BAGLE developments: Hunter Harling, Abby Schleigh, and Dex Bhadra

github.com/MovingUniverseLab/BAGLE_Microlensing

Summary

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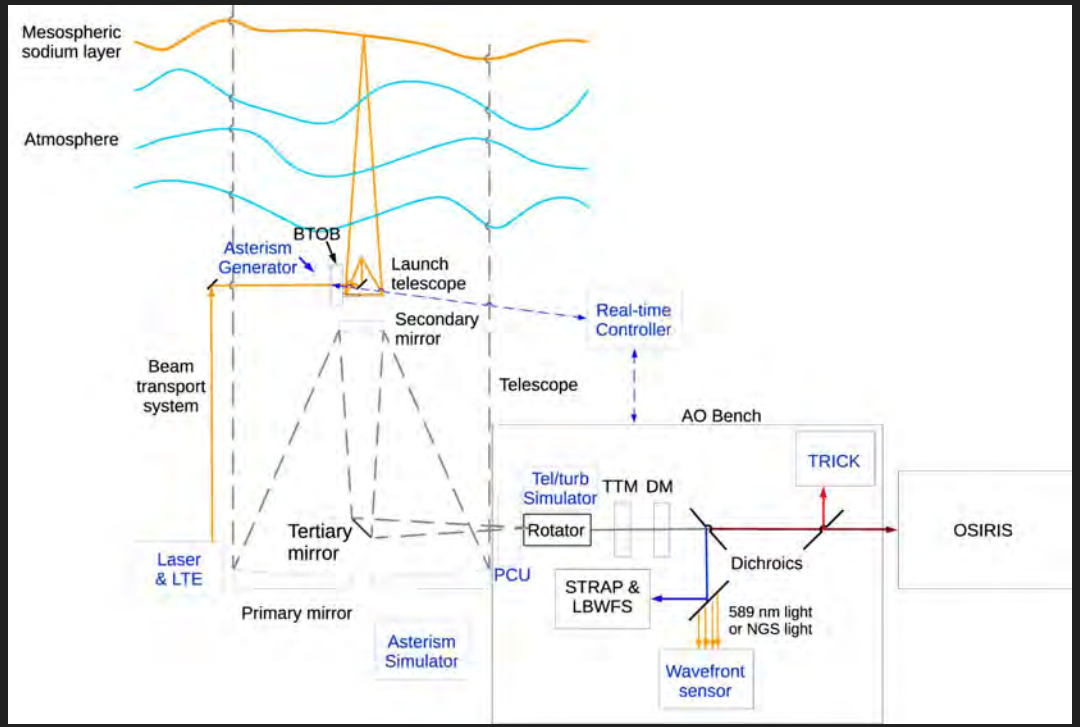
- Our current procedure for finding isolated stellar mass black holes is to select candidates from photometric surveys for astrometric follow-up.
- LS^4's Galactic plane survey will begin in ~Spring 2024 and is expected to observe ~1,300 microlensing events in the first year.
- Re-analysis of Keck AO astrometry is in progress for 4 long-timescale microlensing events, with preliminary results suggesting 2 detections of astrometric shifts, 1 likely to be caused by a black hole or neutron star.

OSIRIS Distortion Solution

- Aberrations in the optical path through the telescope and instrument can decrease astrometric accuracy.
- We can remove this effect with a distortion solution.

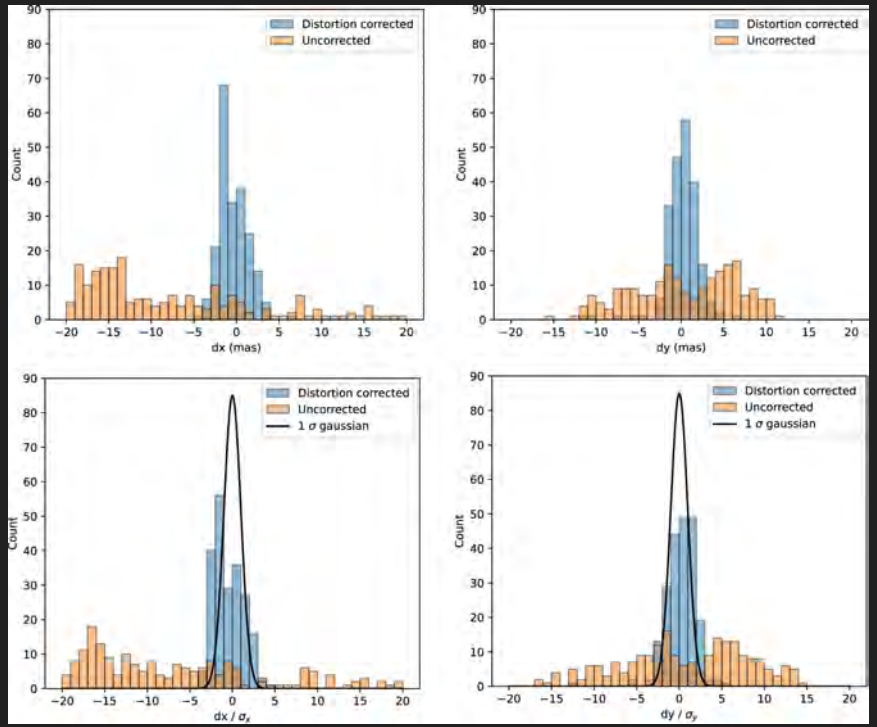


Keck-Osiris diagram (Freeman et al., 2023)

OSIRIS Distortion Solution

- Aberrations in the optical path through the telescope and instrument can degrease astrometric accuracy.
- We can remove this effect with a distortion solution.
- We are able to combine NIRC2 and OSIRIS data for continuous astrometric data sets

Re-analysis still in progress, and we hope to have exciting results soon!



OSIRIS vs. NIRC2 star locations (Freeman et al., 2023)