Challenging Theory with Roman:
From Planet Formation to Cosmology
July 2024

Probing the stellar graveyard and dark matter with astrometric microlensing

Peter McGill

Scott E. Perkins, James Fardeen, Abby Halasi-Kun, William A. Dawson, Natasha S. Abrams, Jessica R. Lu, Ming-Feng Ho, Simeon Bird.

Lawrence Livermore National Laboratory

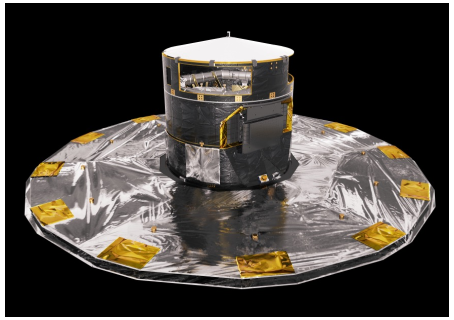
LLNL-PRES-866524

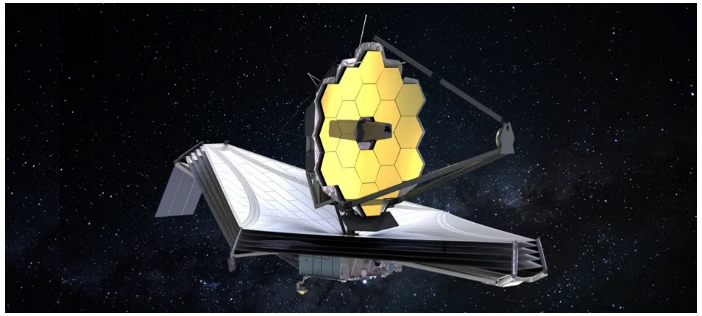
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.
Lawrence Livermore National Security, LLC

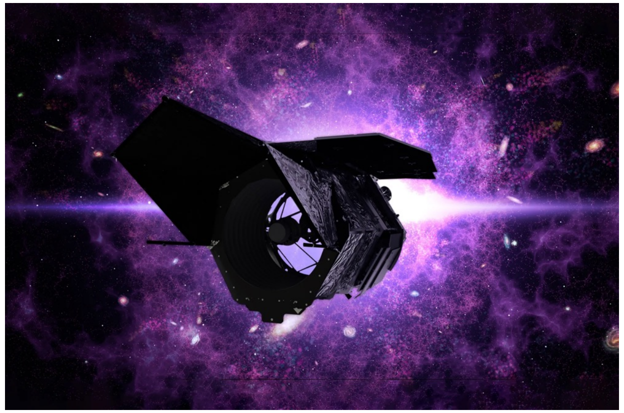
We are in the golden era of high-precision astrometric observatories

We now have several sub-mas astrometric precision space observatories

- Gaia will complete its decade-long astrometric survey of the entire sky this year
- Roman will start the Galactic Bulge Time Domain Survey (GBTDS)
- HST, JWST, Roman & Euclid as astrometric follow-up resources.







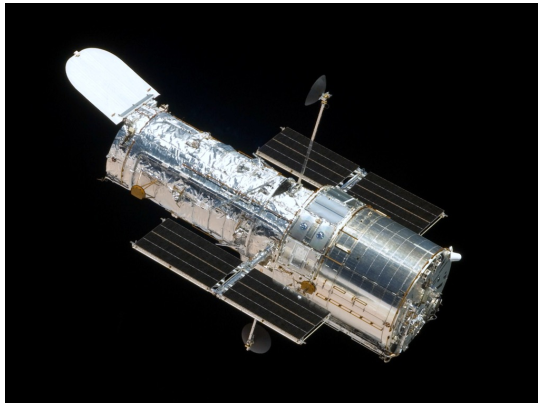


Image credit NASA/ESA

Microlensing provides a window into dark and isolated Galactic populations

- No flux from the object we are studying is required, nor a companion

- Can probe mass, distance, and velocity distributions of dark objects in the Galaxy

- Only viable way to detect dark and isolated objects - black holes, neutron stars, Compact dark matter, free-floating planets.

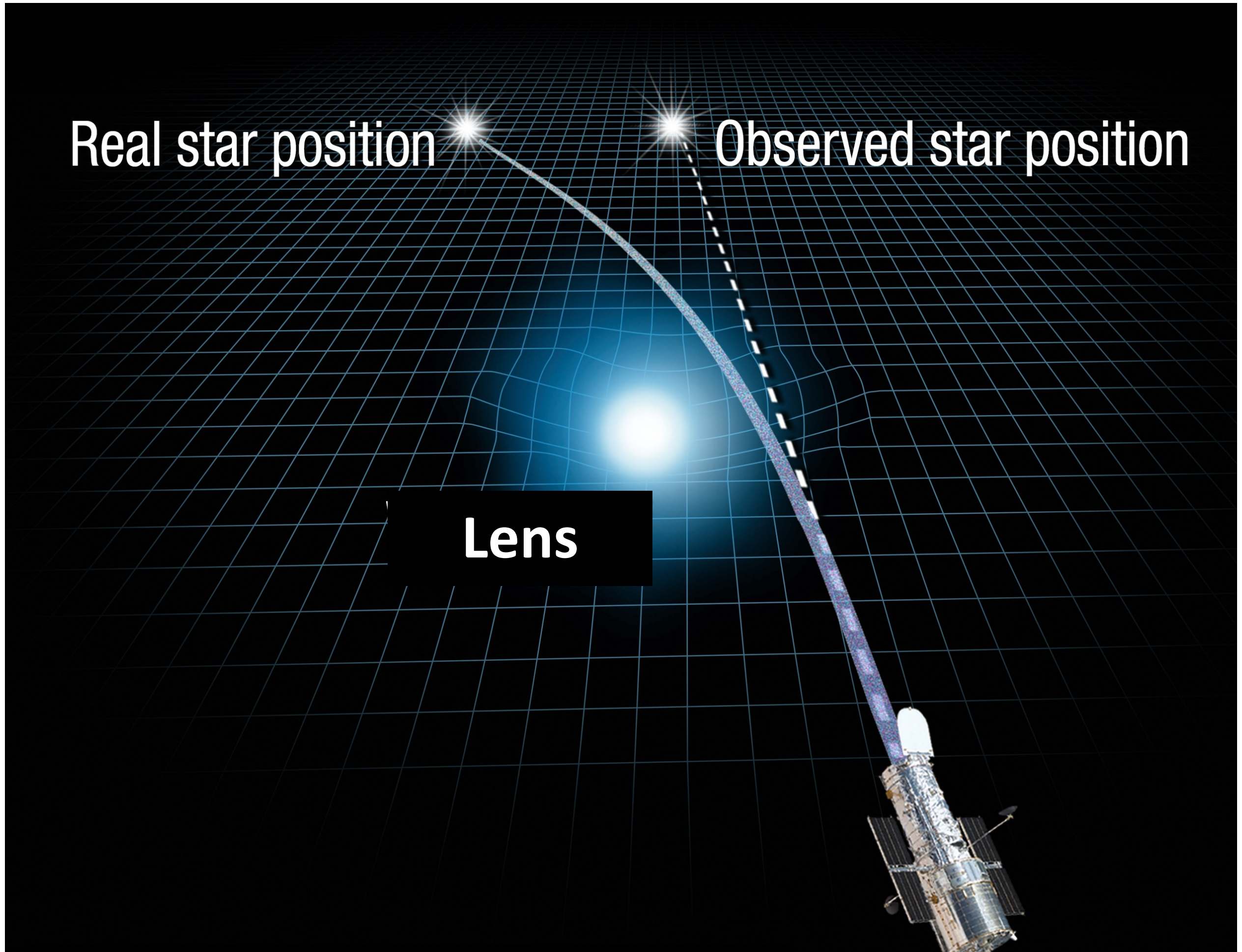
Photometric vs Astrometric microlensing

Photometric

- Timescales ~ days – months
- Signal size can be (almost) arbitrarily large for decreasing lens-source separations
- Signal peaks at closest lens source separation

Astrometric

- Timescales ~ months – years
- Signal size is fundamentally limited by the size of θ_E
- Signal can peak before and after lens source separation

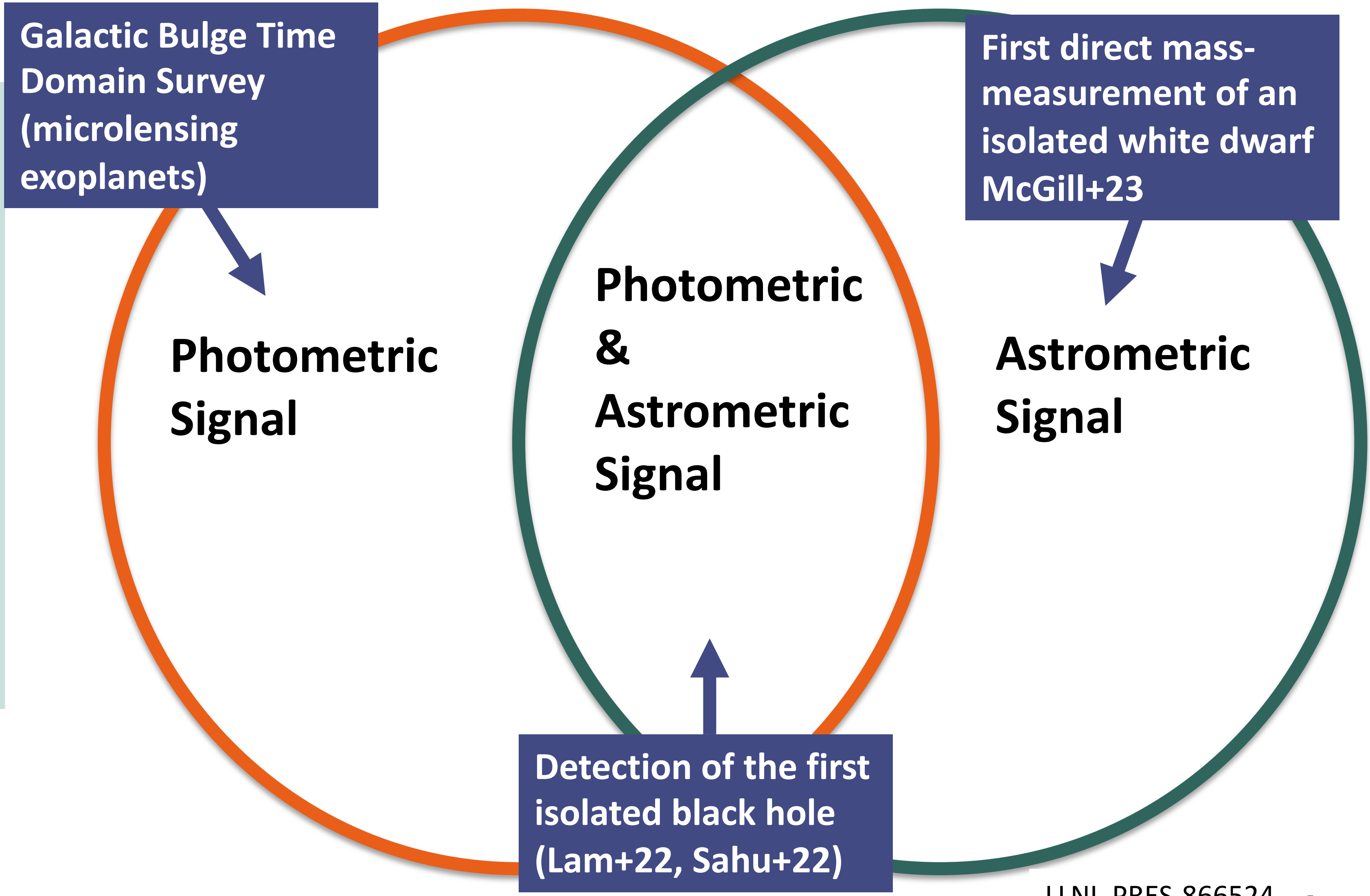


NASA, ESA, Ann Feild (STScI)

Detection channels

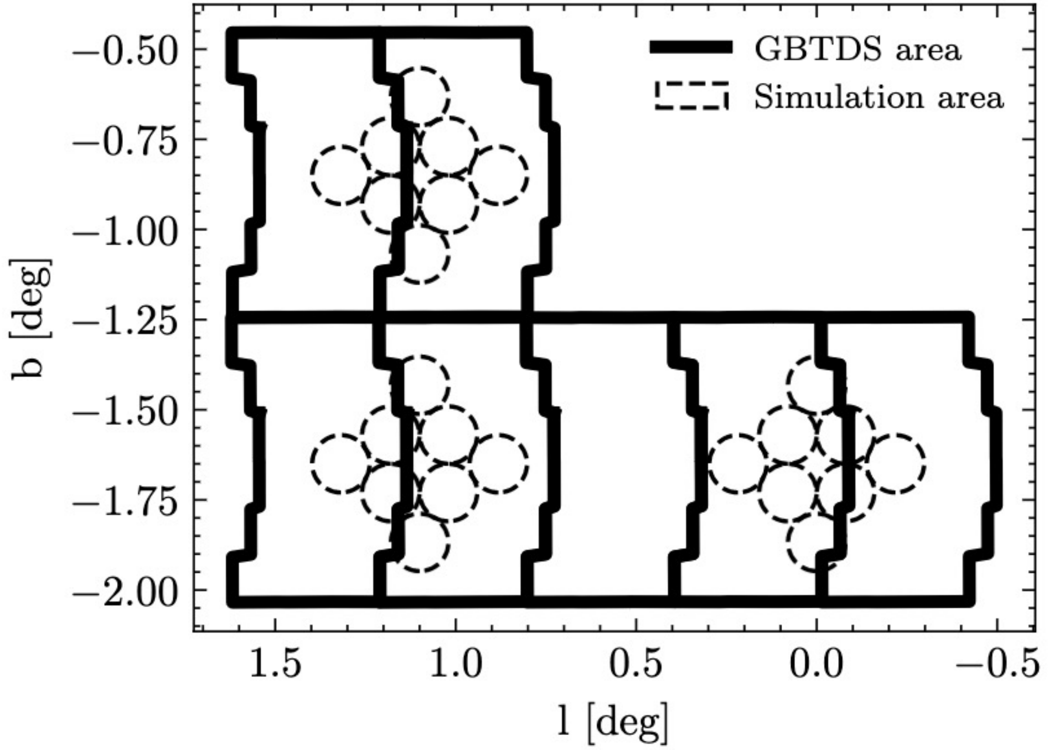
The different channels have:

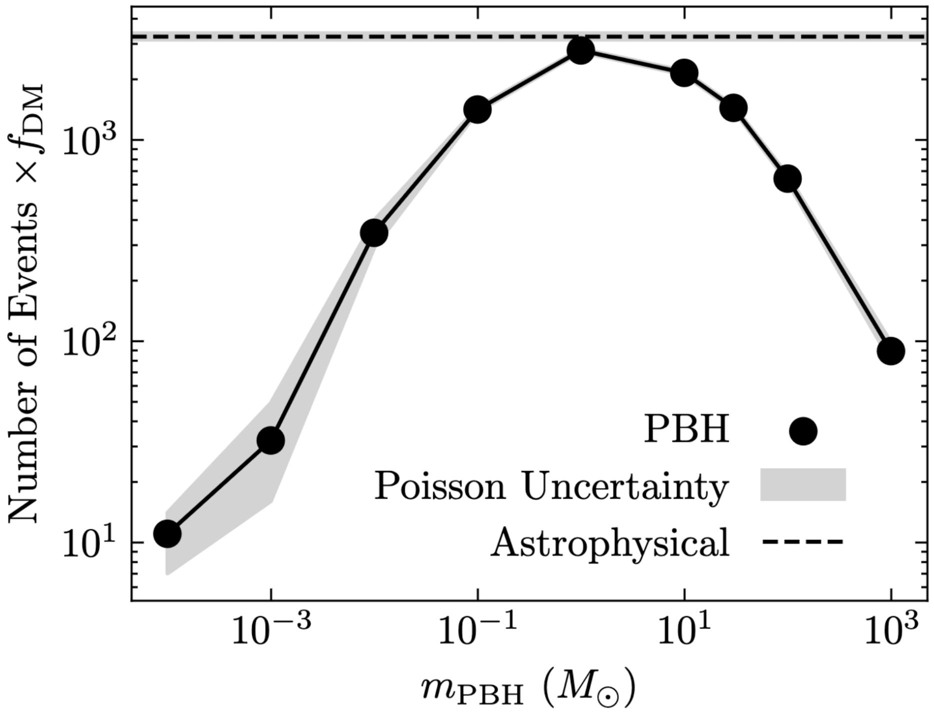
- Different rates
- Different information content
- Different costs to pursue
- Different timescales
- Different follow-up strategies



Prospects for detecting primordial black holes with Roman

Simulated Galactic Bulge Time Domain Survey (~wide separation u0> 2, ~astrometric only)





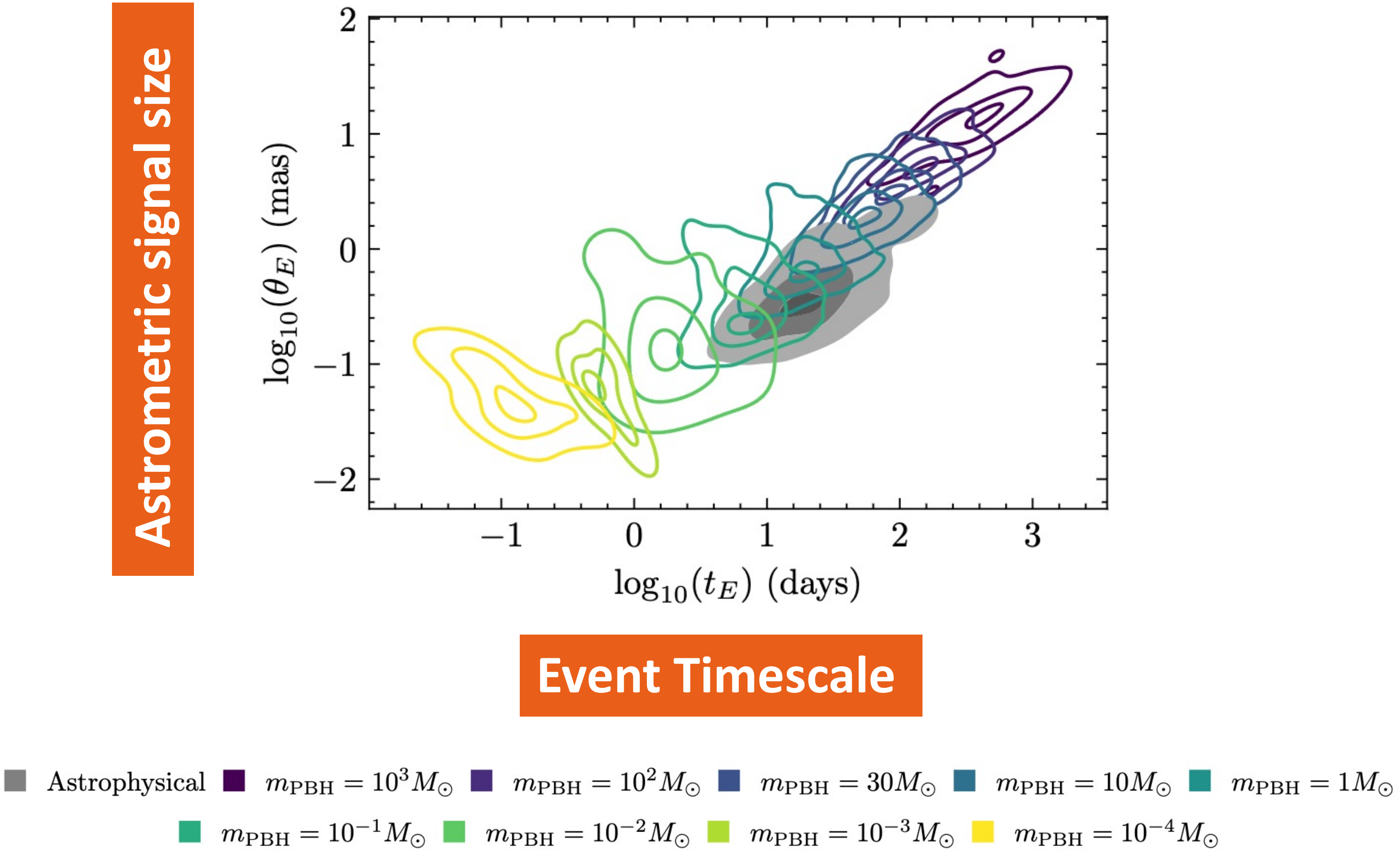
The Astrophysical Journal, 965:138 (15pp), 2024 April 20 https://doi.org/10.3847/1538-4357/ad3243

CrossMark

Astrometric Microlensing by Primordial Black Holes with the Roman Space Telescope

James Fardeen[1], Peter McGill[1], Scott E. Perkins[1], William A. Dawson[1], Natasha S. Abrams[2], Jessica R. Lu[2], Ming-Feng Ho[3], and Simeon Bird[3]
[1] Space Science Institute, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA; mcgill5@llnl.gov
[2] University of California, Berkeley, Astronomy Department, Berkeley, CA 94720, USA
[3] Department of Physics and Astronomy, University of California, Riverside, 900 University Avenue, Riverside, CA 92521, USA
Received 2023 December 20; revised 2024 February 23; accepted 2024 March 8; published 2024 April 16

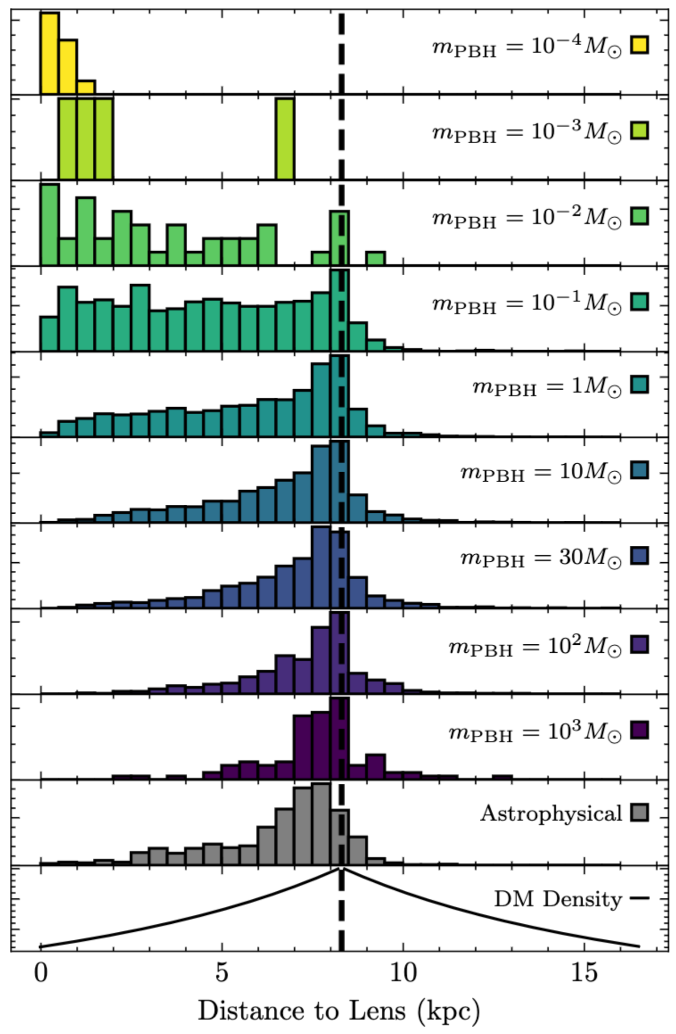
Intrinsic separability of lenses



Configuration of the detectable lenses

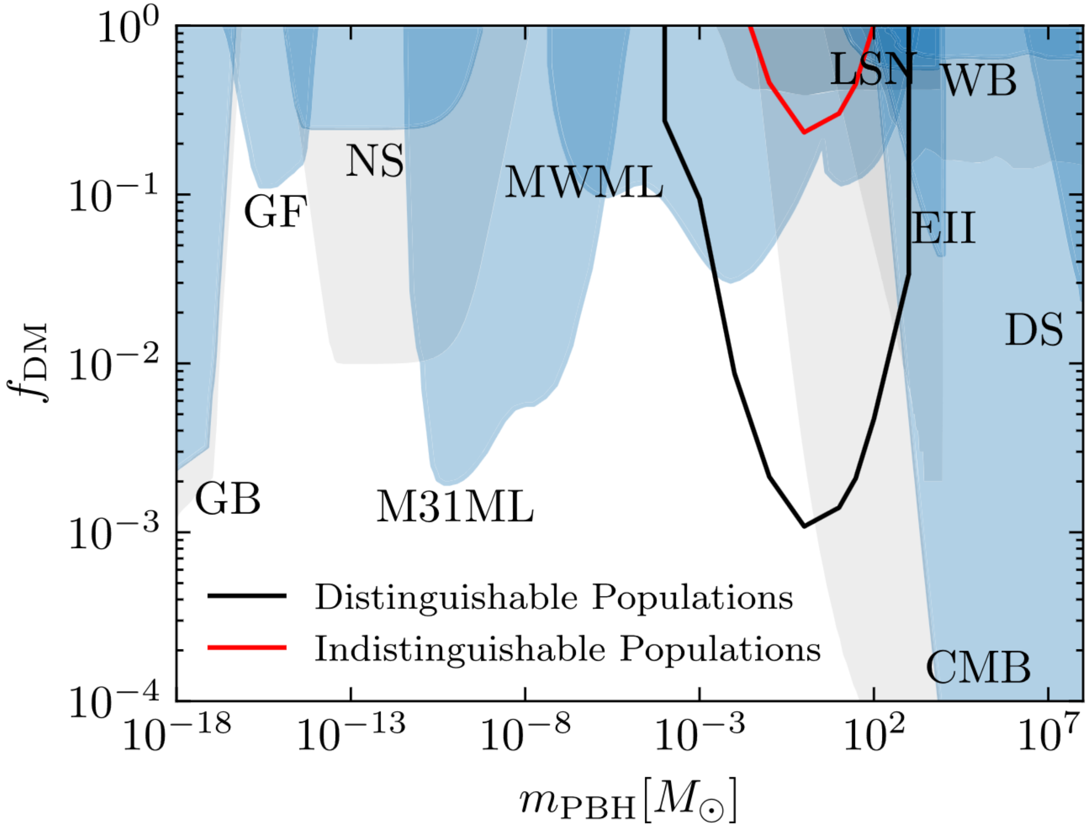
- Number of low-mass PBHs events is volume limited. They need to be close by to have large enough $\boldsymbol{\theta}_E$ to be astrometrically detectable.

- Number of high-mass PBHs events are limited by the duration of the GBTDS, astrometric signals vary too slowly to be detectable within 5 years.



Projected dark matter constraints

- Potential for novel PBH constraints & cross check on previous photometric constraints
- Low mass end is limited by number of lenses closes enough to have detectable astrometric signal
- High-mass end is limited by duration of GBTDS



Astrometric lensing by the astrophysical population (u0>2)

Predicted Yields:

All: ~ 3200

Black Holes:~330

Neutron Stars:~310

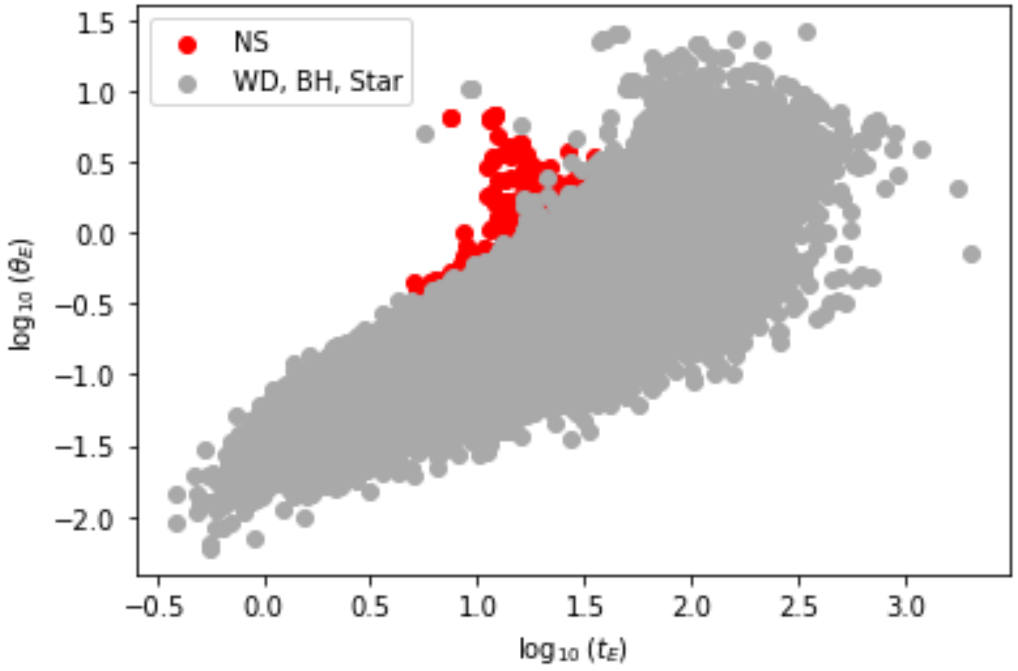
This is ~ the same as the yield of close separation photometric & astrometric events.

Lam+23 CCS white paper:

Black Holes:~270

Neutron Stars: ~120

Astrometric signal size

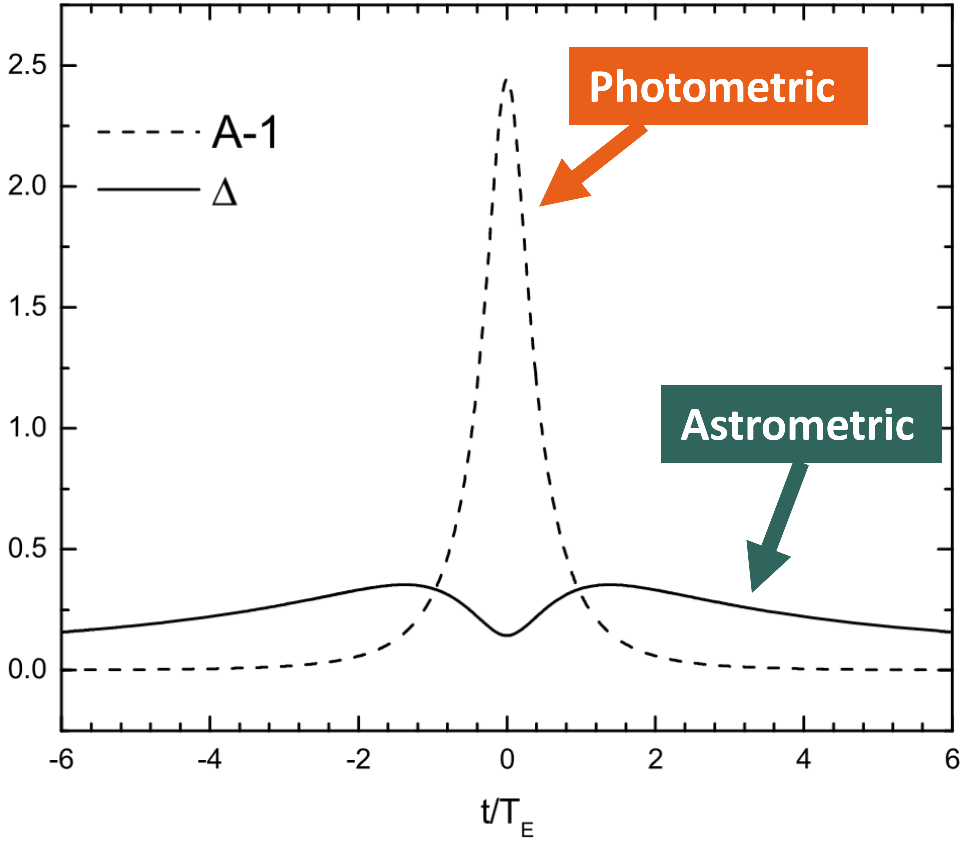


Event Timescale

McGill, Halasi-Kun +(in prep)

Exploiting the synergies of the astrometric and photometric signals to increase the yield of interesting lenses

- Astrometric & photometric signals are not simultaneous. Do we get an astrometric warning of an impending photometric event? Is that useful?
- Filling in the gaps of the GBTDS and synergies with ground based surveys (e.g., LSST) have been explored photometrically, what about astrometrically?
- All this will require some "real-time" astrometric processing of the Roman data stream



Hamolli+18

Summary

- Roman will detect ~10^3 $u_0>2$ astrometric microlensing events for all lens types which will be missed by photometric-only processing
- Potential for novel PBH dark matter constraints with the GBTDS
- There are a lot of opportunities to exploit synergies of the photometric **and astrometric** signals to increase the yield of interesting lenses with upcoming surveys
- The (unrealistic?) dream: transient astrometric alerts for Roman. The sub-mas transient astrometric sky has never been explored in real-time.

Space Science Institute
Lawrence Livermore National Laboratory