Black Hole Microlensing: Rubin-Roman Joint Pixel Processing and Temporal Complementarity

Joint Survey Processing AAS Splinter Session

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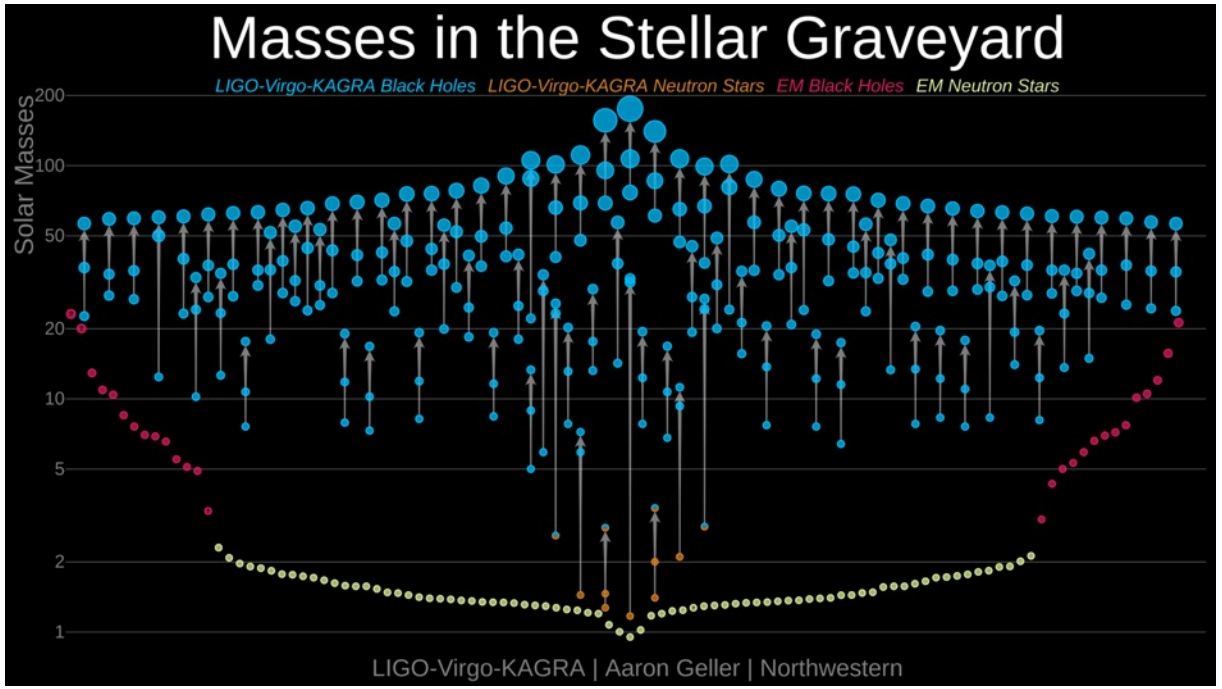
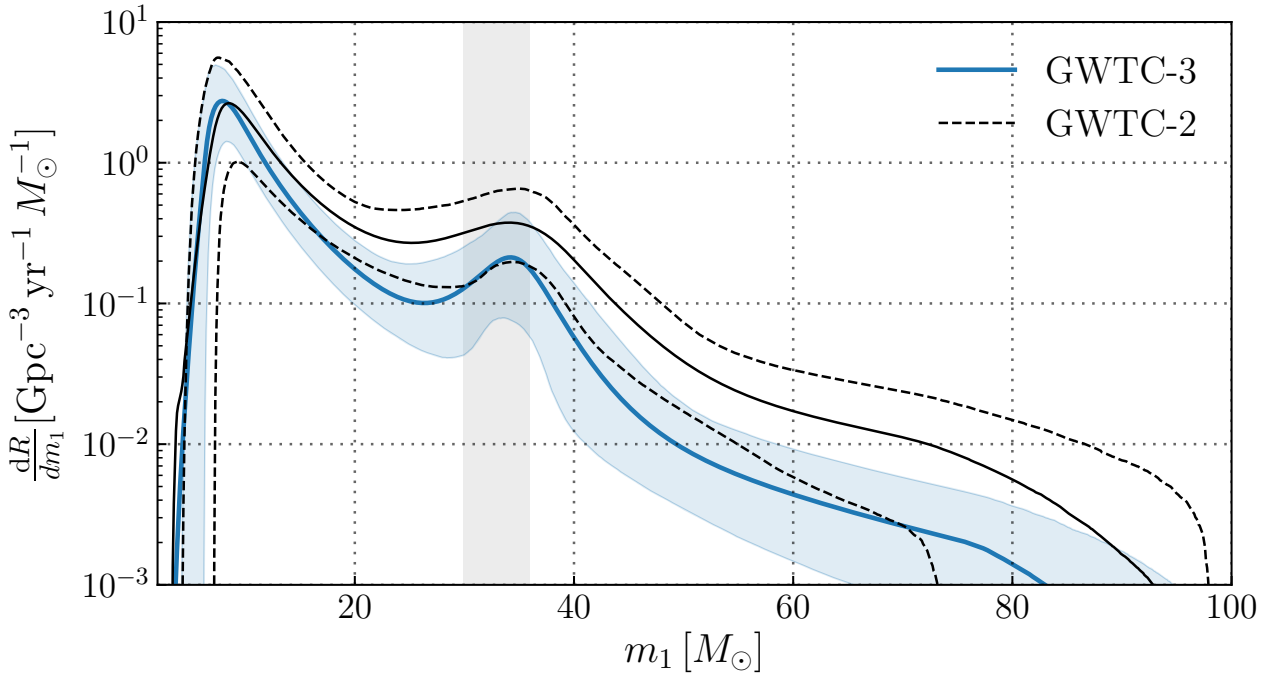
Lawrence Livermore National Laboratory

Significant evidence for two populations of black holes from Gravitational Wave Transient Catalog 3… why?



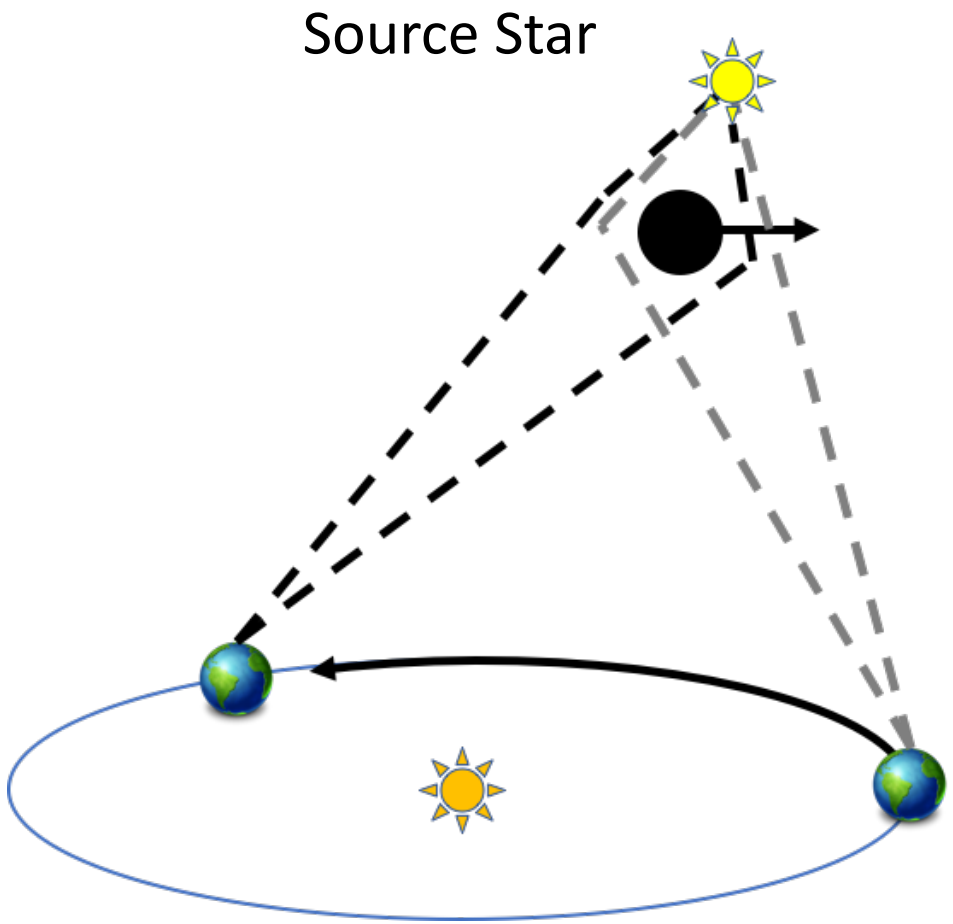


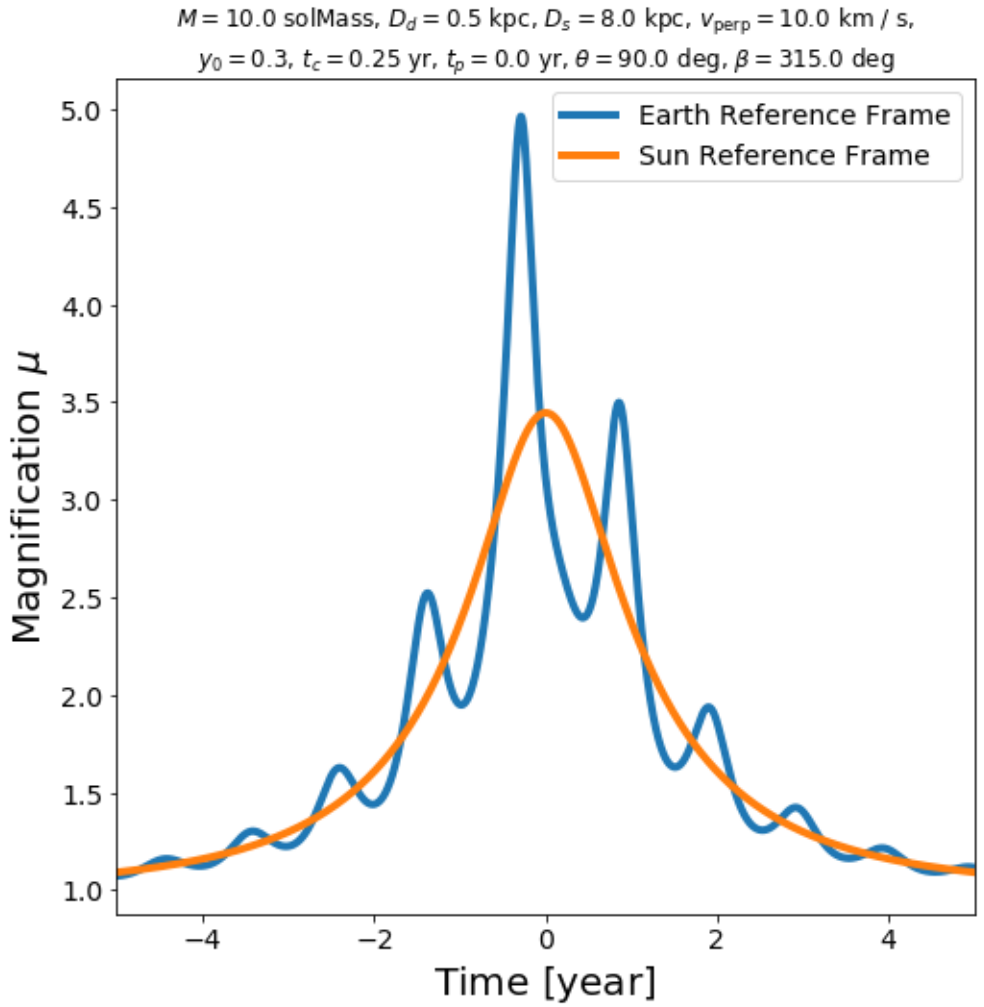
Based on 76 black hole – black hole merger signals.

If we could observe these objects in the Milky Way we could determine if the two populations populate similar regions.

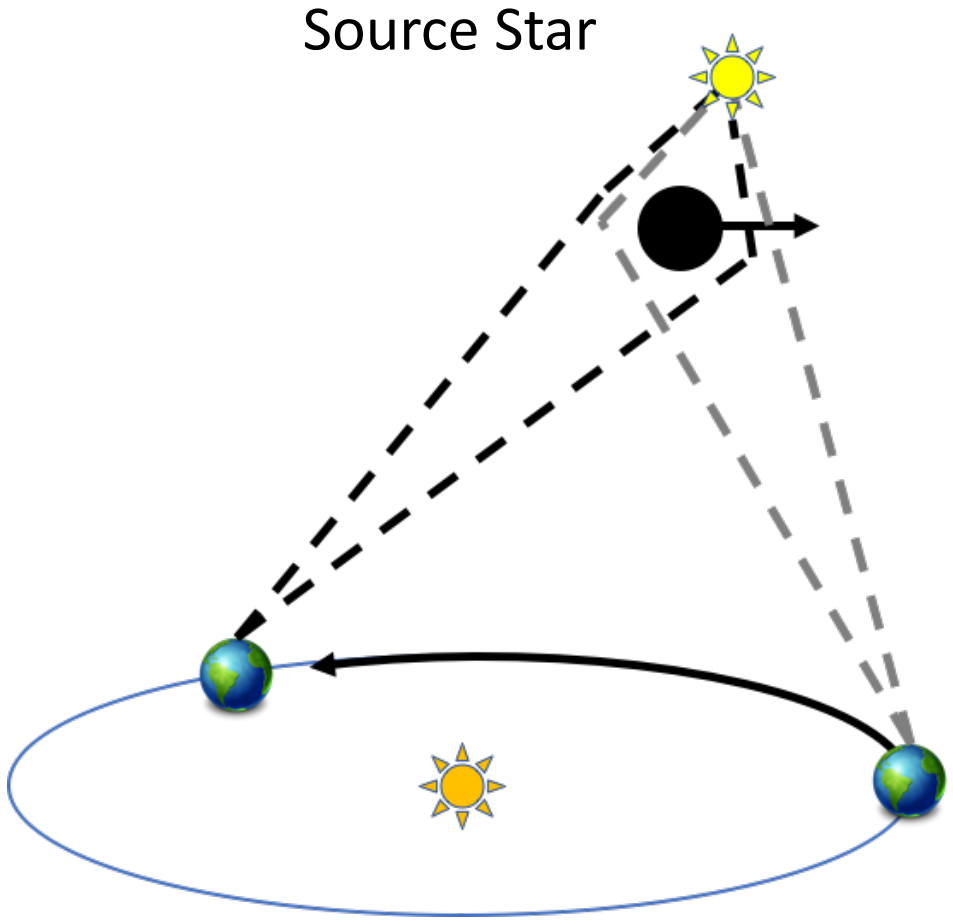
arXiv:2111.03634

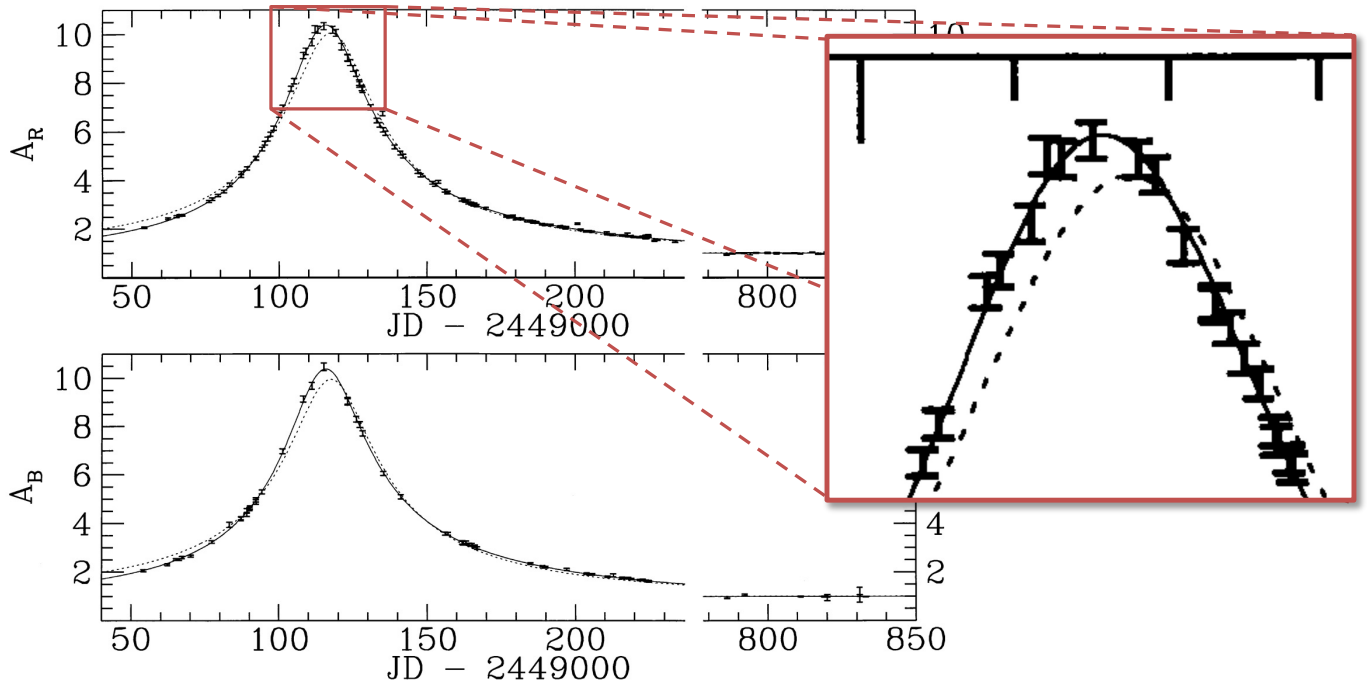
An important secondary microlensing signal: Parallax a multi-year lensing events with 6-month periodic signal





Most parallax signals are relatively small perturbations on the simple heliocentric model

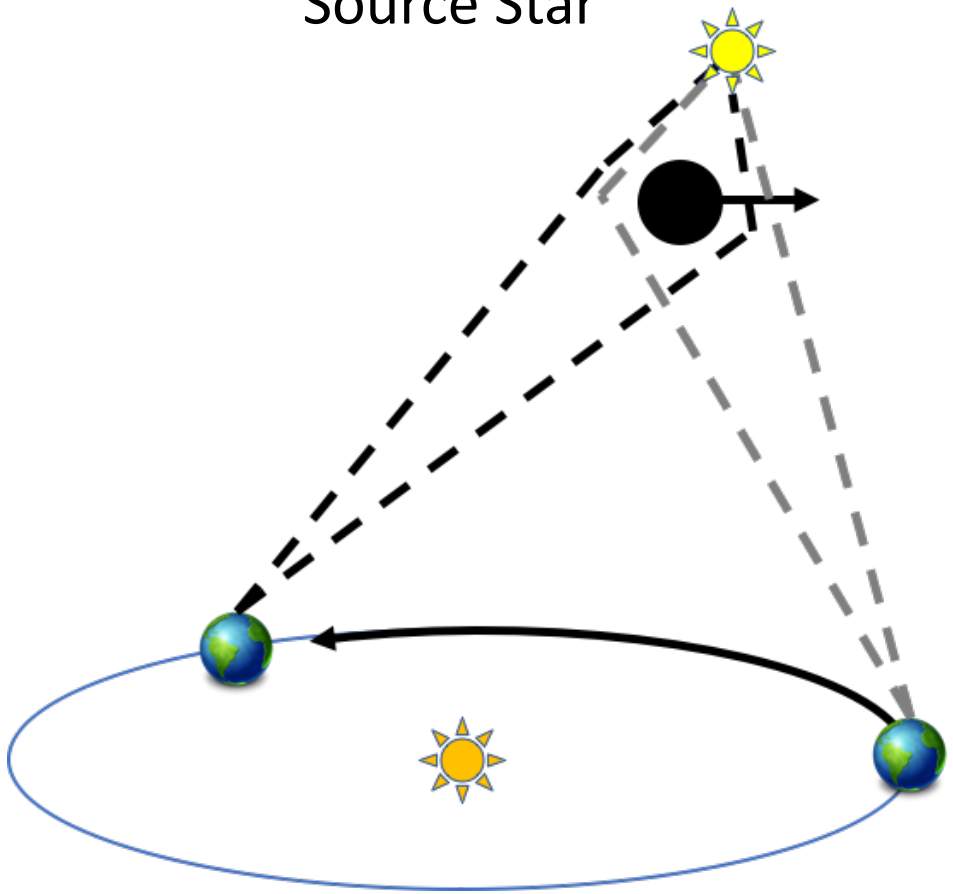




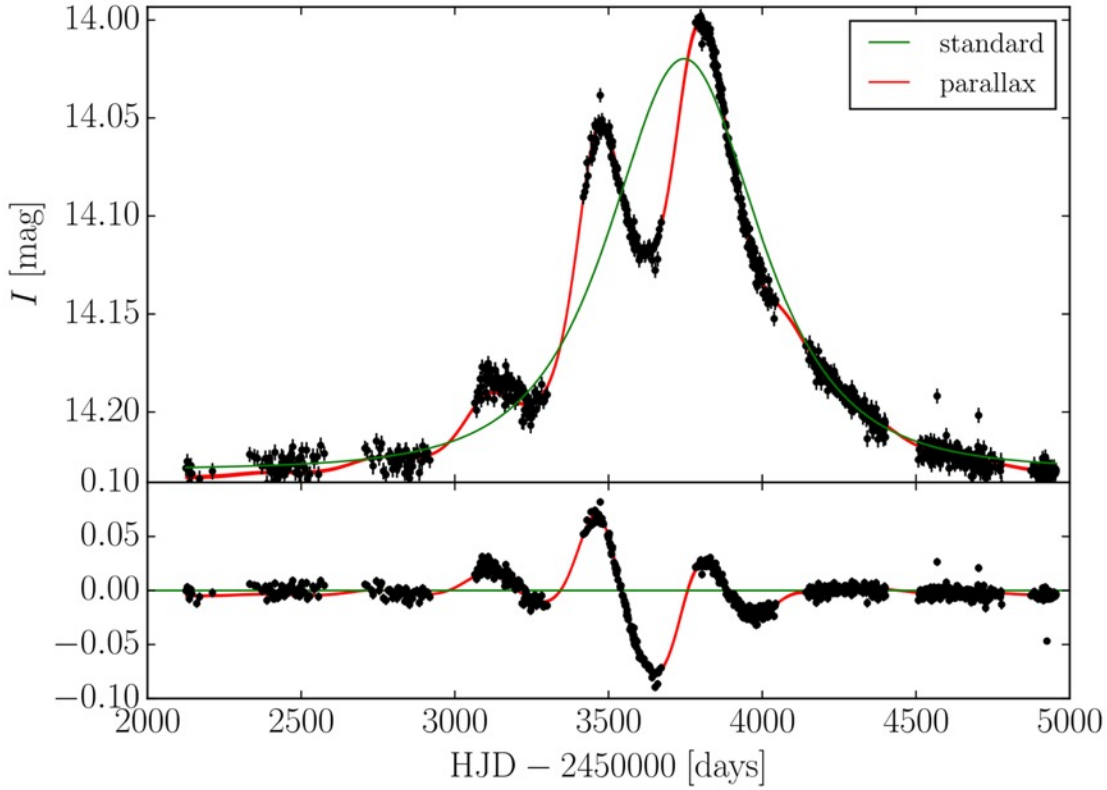
MACHO Survey (1995)

There are some observed high parallax events

Source Star

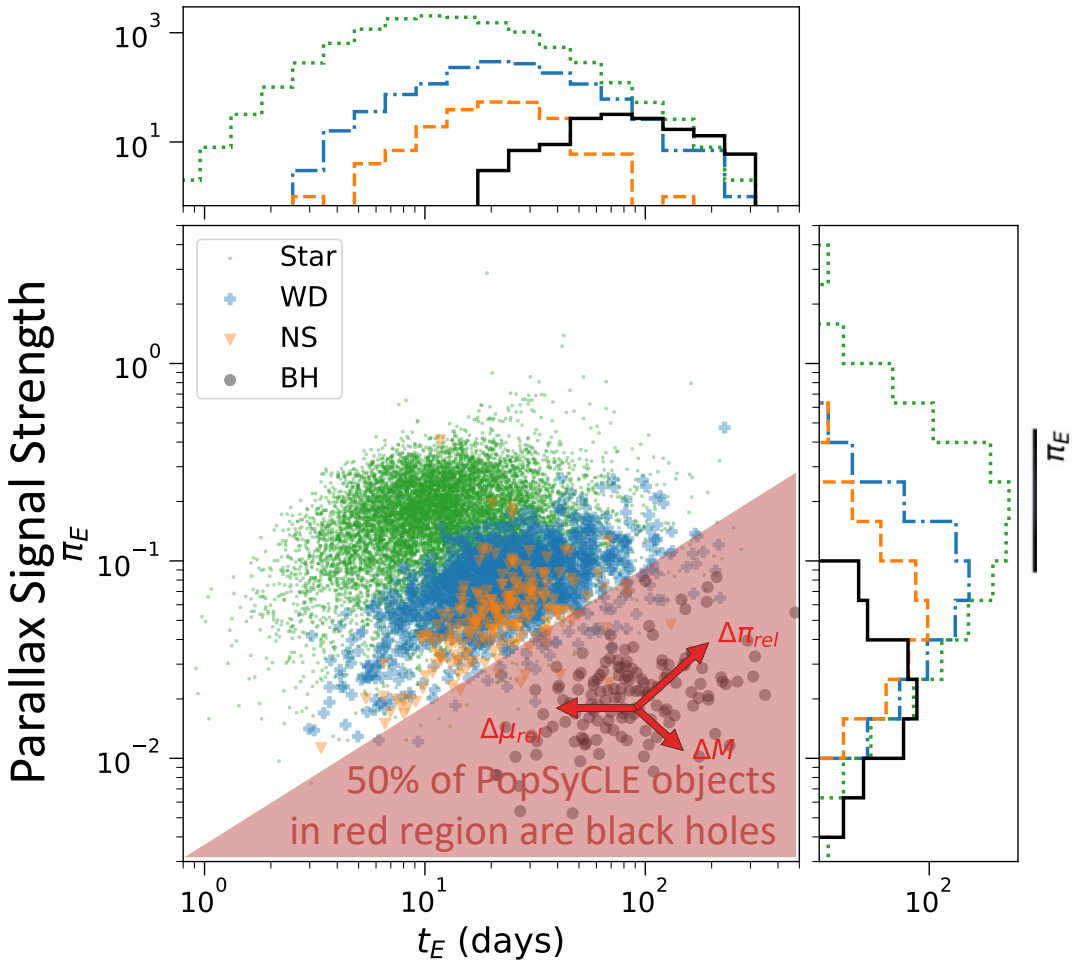


1.0 $M_\odot$ Neutron Star



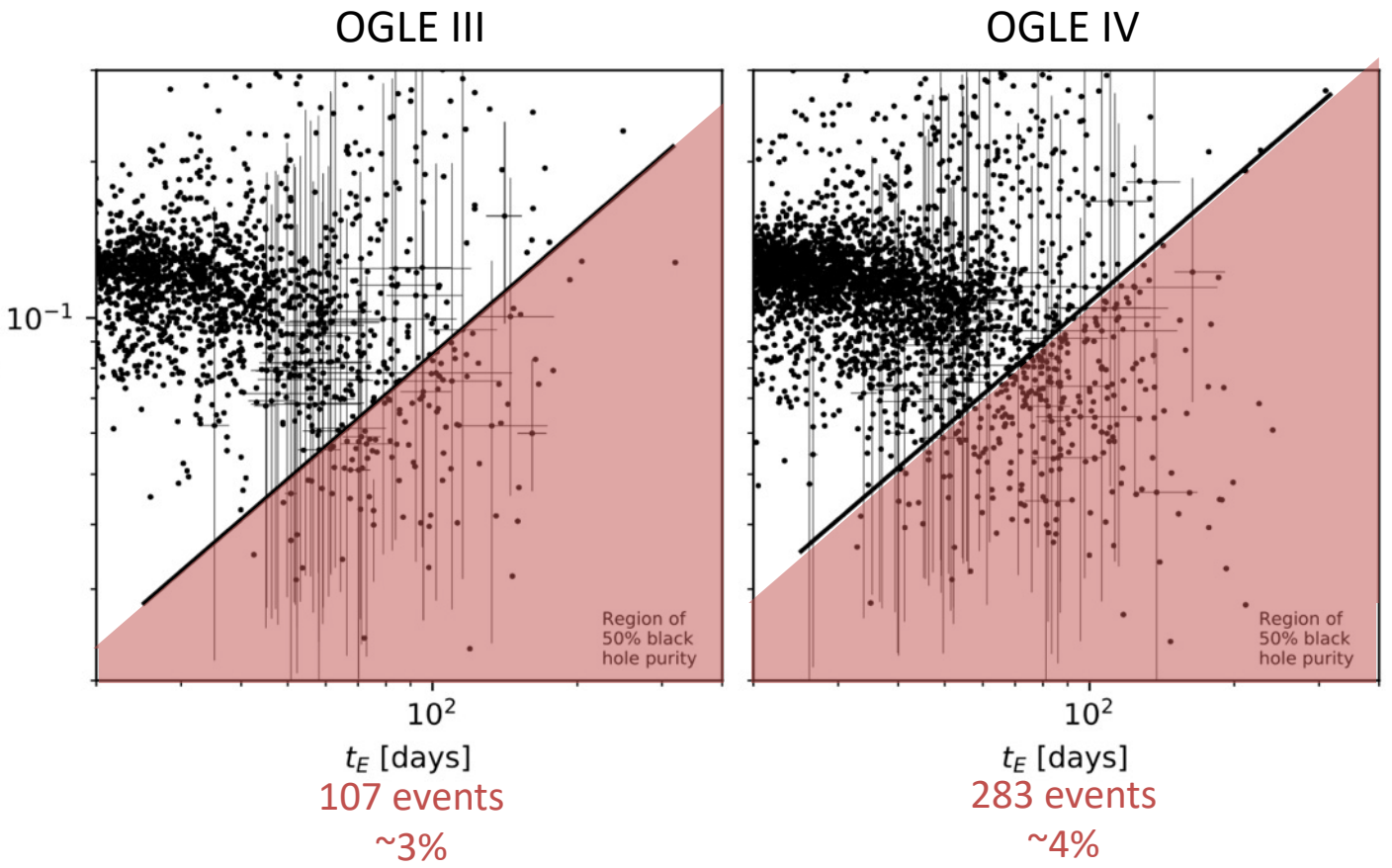
Wyrzkowski et al. 2016

A new way to find many more black holes in the Milky Way



Lam et al. 2020

Event Duration

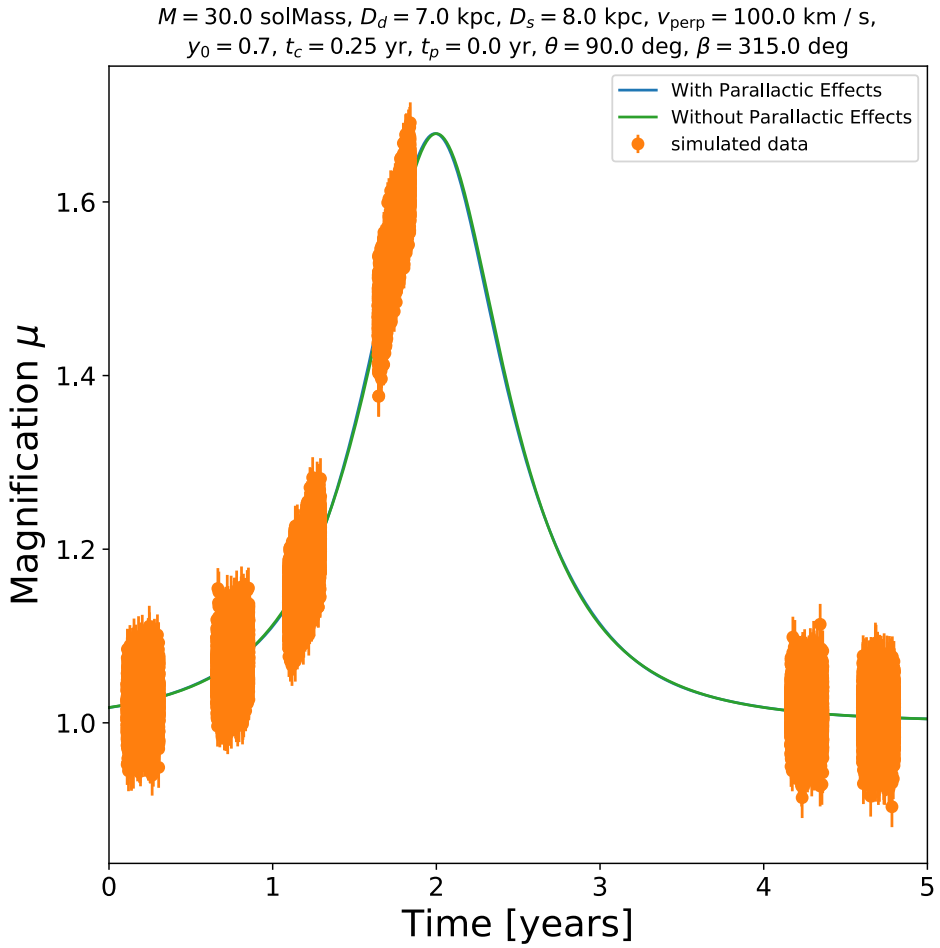


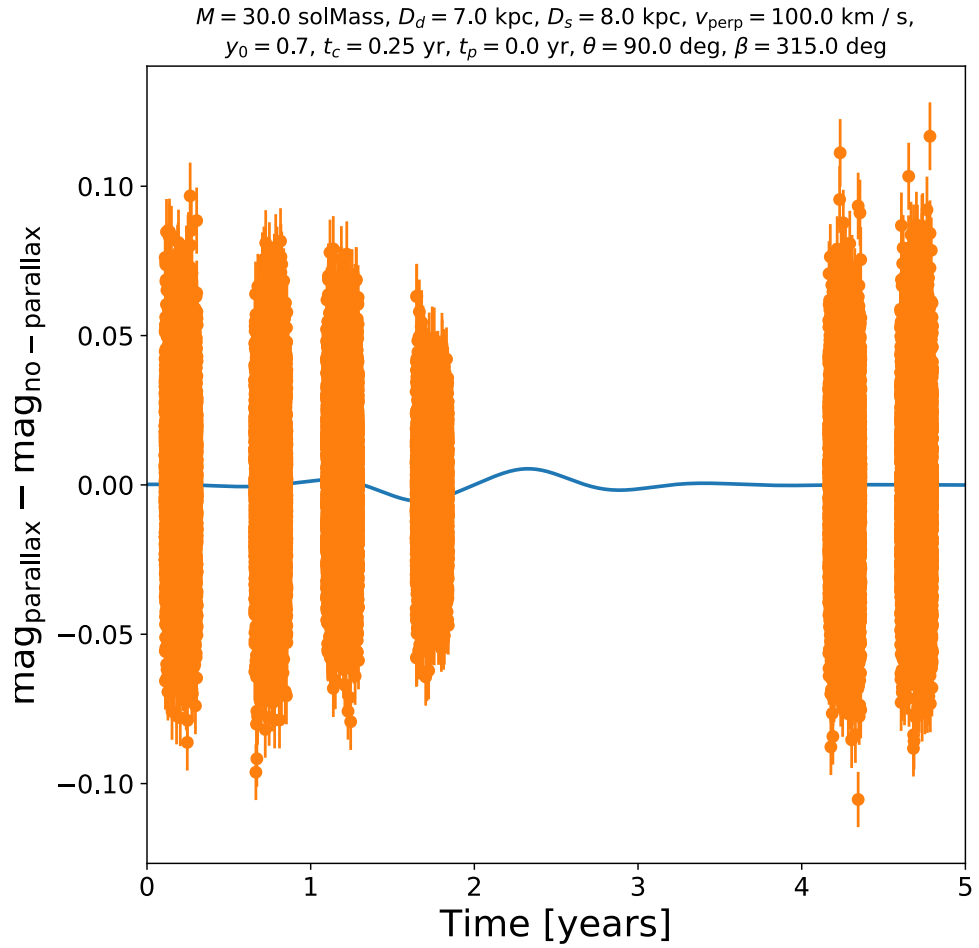
107 events
~3%

283 events
~4%

Golovich, WD, et al. (2020)

Simulated 30 $M_\odot$ black hole lensing
22nd W149 magnitude source star observed by Roman





Based on 2017 survey plan.

Simulated 30 $M_\odot$ black hole lensing
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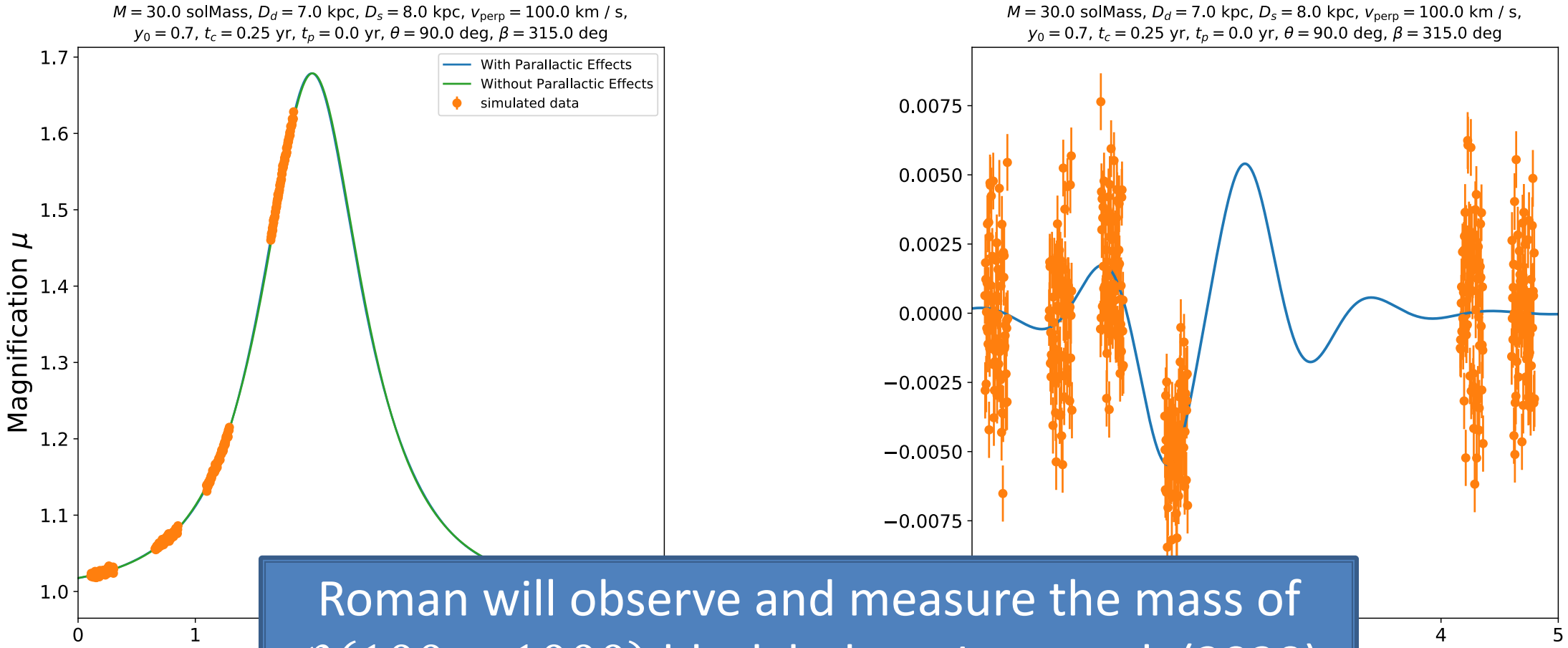
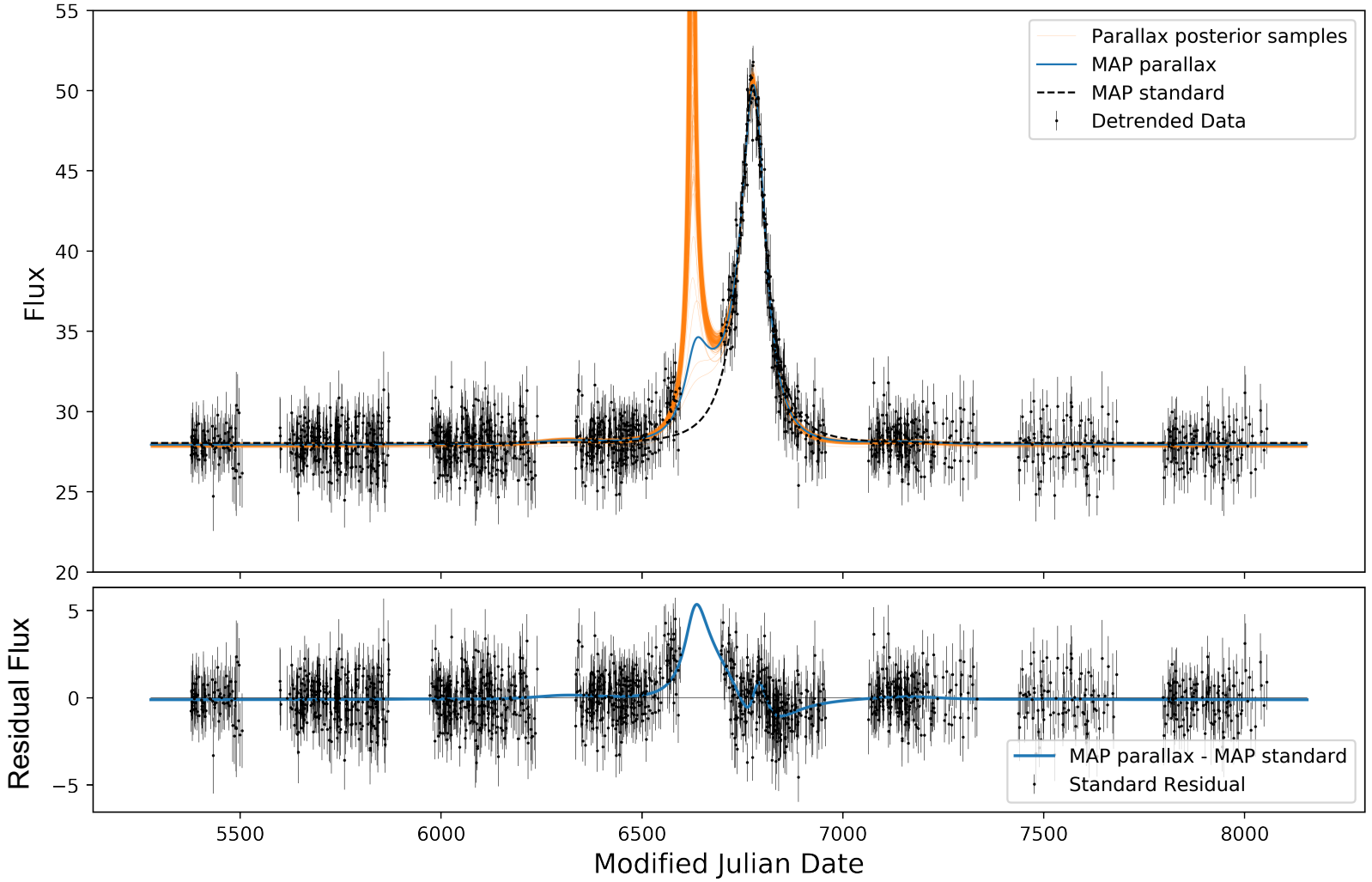


Roman will observe and measure the mass of $\mathcal{O}(100 - 1000)$ black holes. ~Lam et al. (2020)

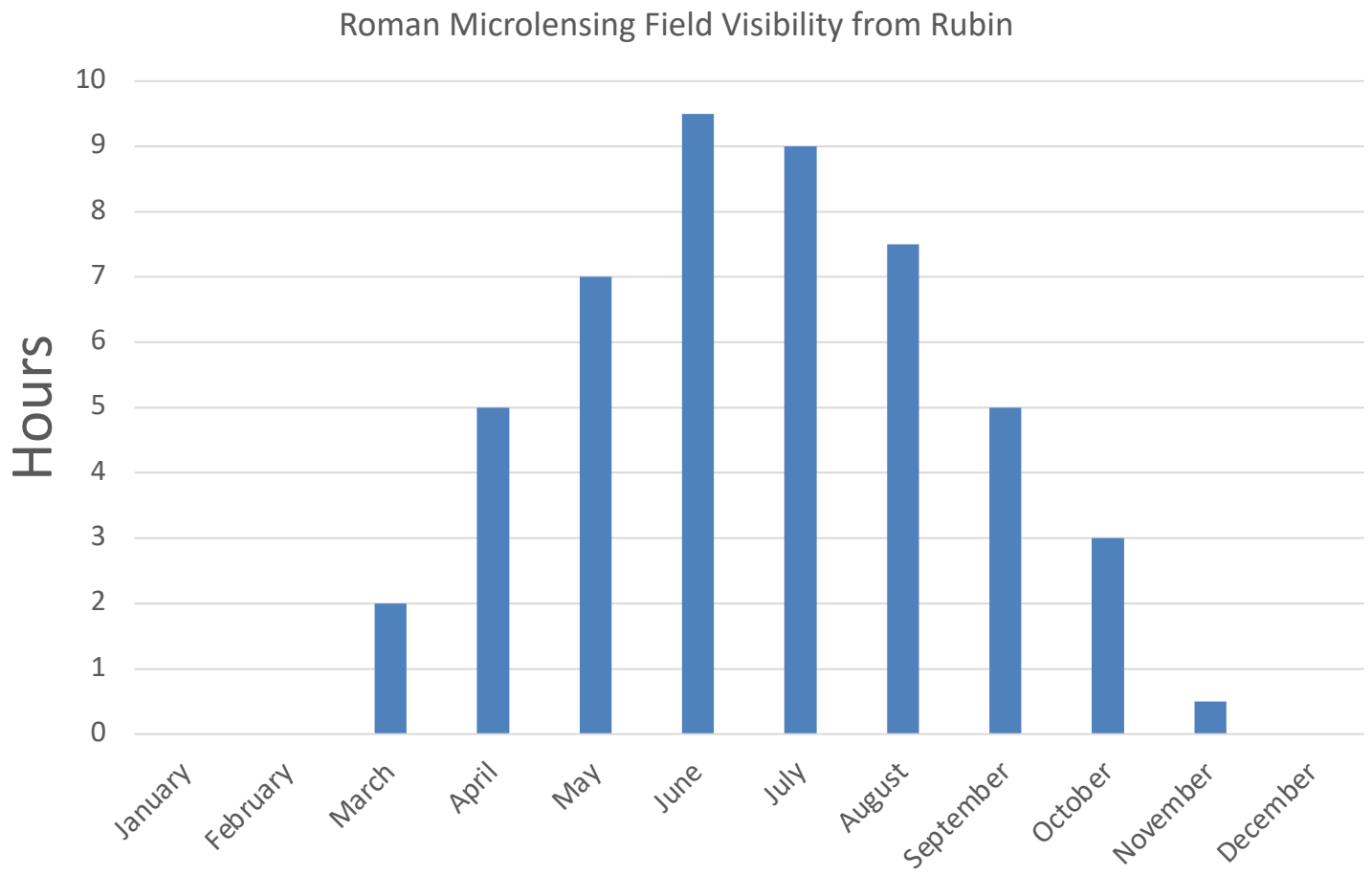
Based on 2017 survey plan.

Gaps in the data can produce large parallax uncertainty



Golovich, WD, et al. (2020)

Rubin can fill many of the Roman gaps but requires high-level project coordination (task for TAG?)



Although the fields still pass close to the ecliptic so some gaps will remain

The Rubin Survey Cadence Optimization Committee is in final phase of determining how much to overlap with Roman

The Diverse Science Return from a Wide-Area Survey of the Galactic Plane

R.A. Street, M.B. Lund, S. Khakpash, M. Donachie, W.A. Dawson,

N.

Unique Science from a Coordinated LSST-WFIRST Survey of the Galactic Bulge

R.A. Street, M.B. Lund, M. Donachie, S. Khakpash, N. Golovich, M. Penny, D. Bennett, W.A. Dawson, J. Pepper, M. Rabus, P. Szkody, W.I. Clarkson, R. Di Stefano, N. Rattenbury, M.P.G. Hundertmark, Y. Tsapras, S. Ridgway, K. Stassun, V. Bozza, A. Bhattacharya, S. Calchi Novati,Y. Shvartzvald, with the support of the LSST Transient and Variable Stars Collaboration.

Nov 2018

Survey Cadence Optimization Committee's Phase 1 Recommendation DRAFT

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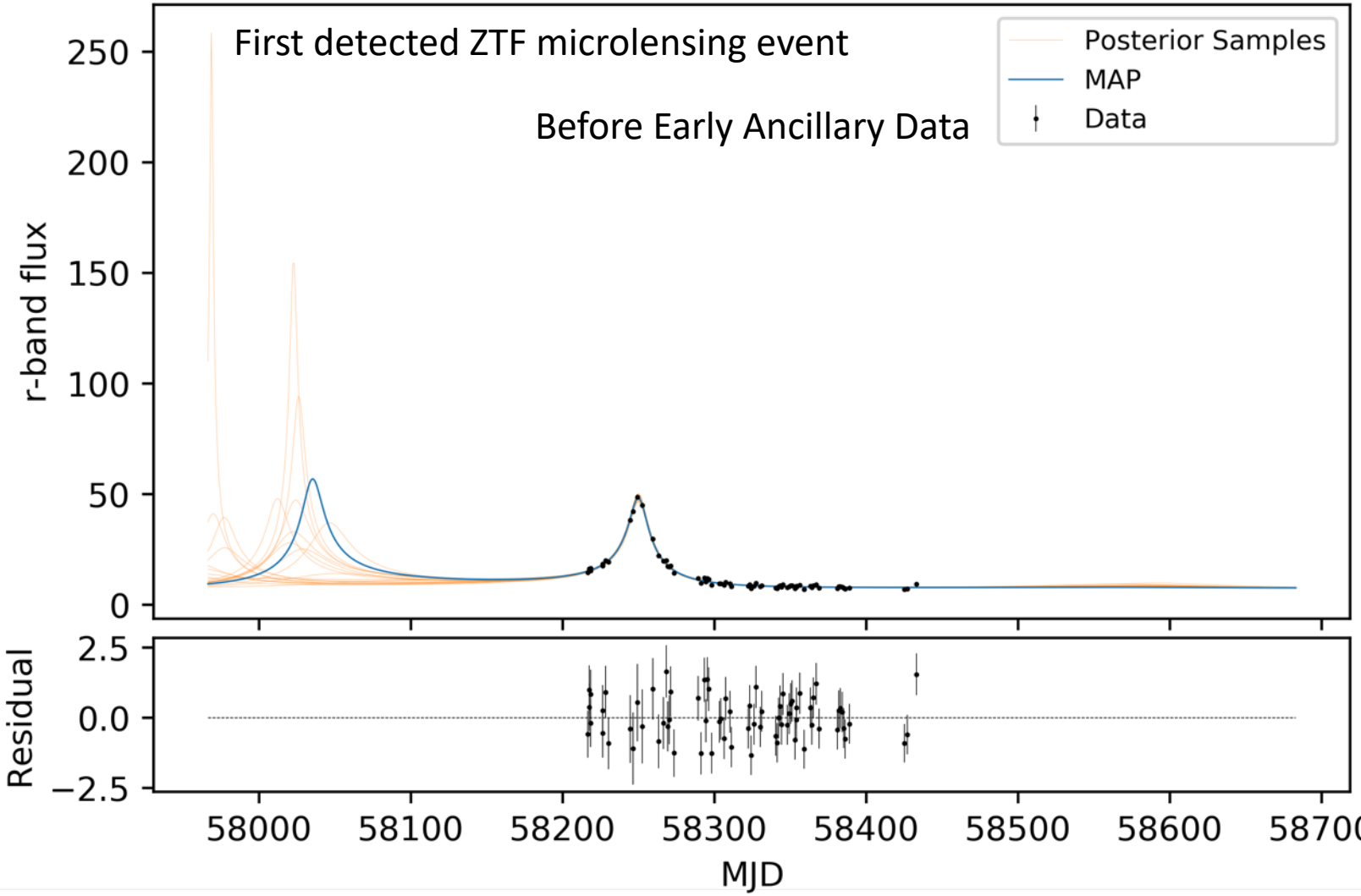
[1] *University of Washington, Dept. of Astronomy, Box 351580, Seattle, WA 98195, USA*

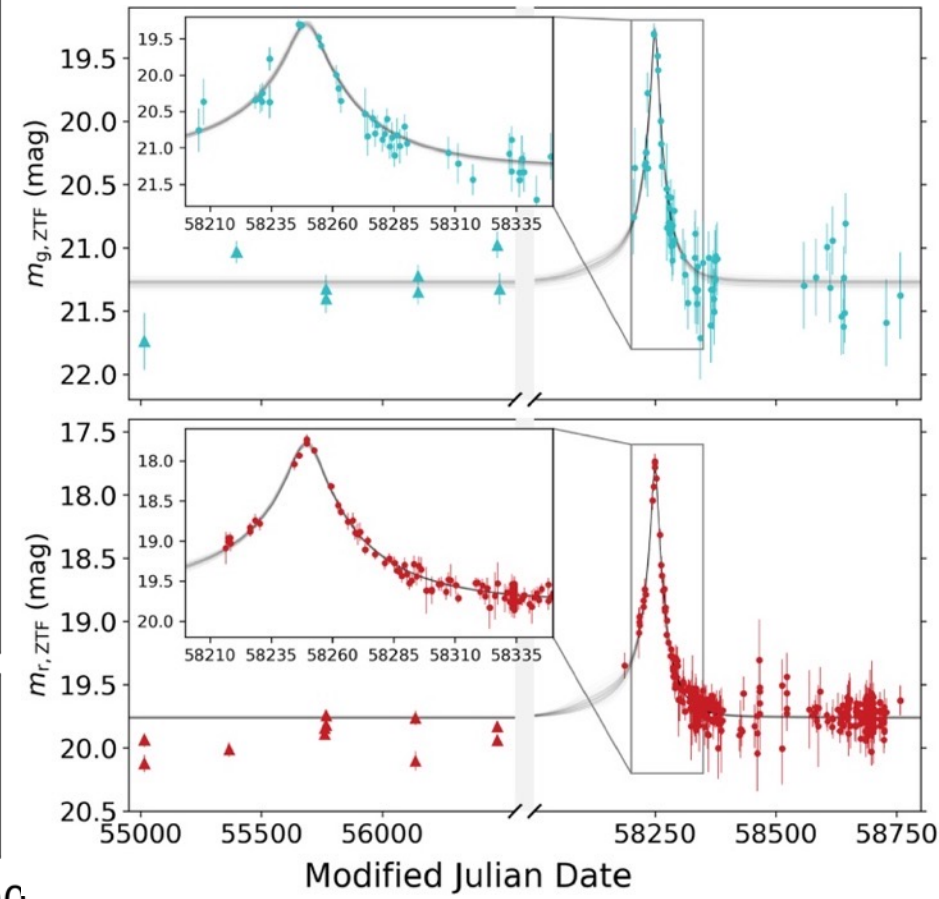
(Dated: December 15, 2021)

time. The micro-surveys requesting above approximately 0.3% of the total survey time include the following nine proposals that the SCOC recommends for simulation in phase 2:

– short description –	– obs. time –
1) short twilight visits for near-Sun objects incl. NEOs	1-3%
2) ToO follow-up to ID counterparts to GW sources	1-2%
3) mini-survey/DDF of Roman microlensing bulge field	2%
4) Limited-visit survey of sky to Dec $< +30$	1%
5) static short exposure map of sky in ugrizy	1%
6) static to transient short exposure survey	1-5%
7) mini-survey of the virgo cluster to WFD depth	1%
8) deeper g-band imaging of 10 local volume galaxies	0.3%
9) high cadence survey of 2 fields in SMC for microlenses	0.3%

It is important to have observations ahead of your survey



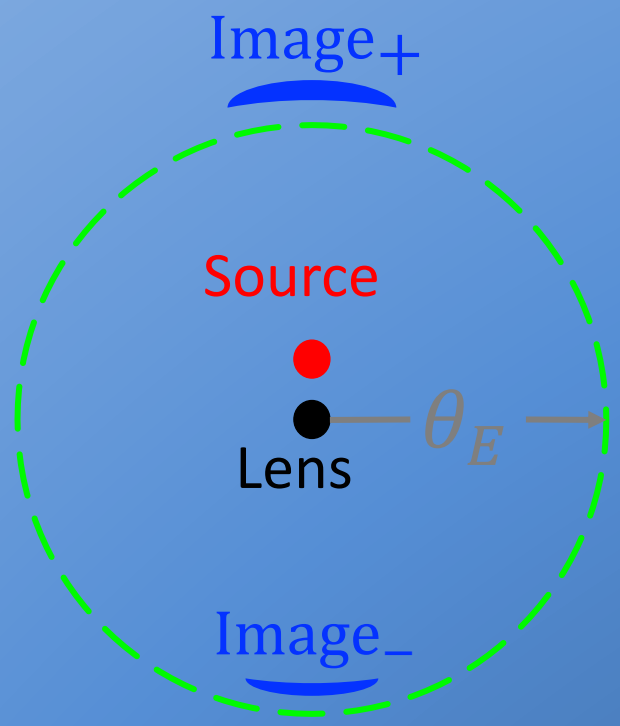


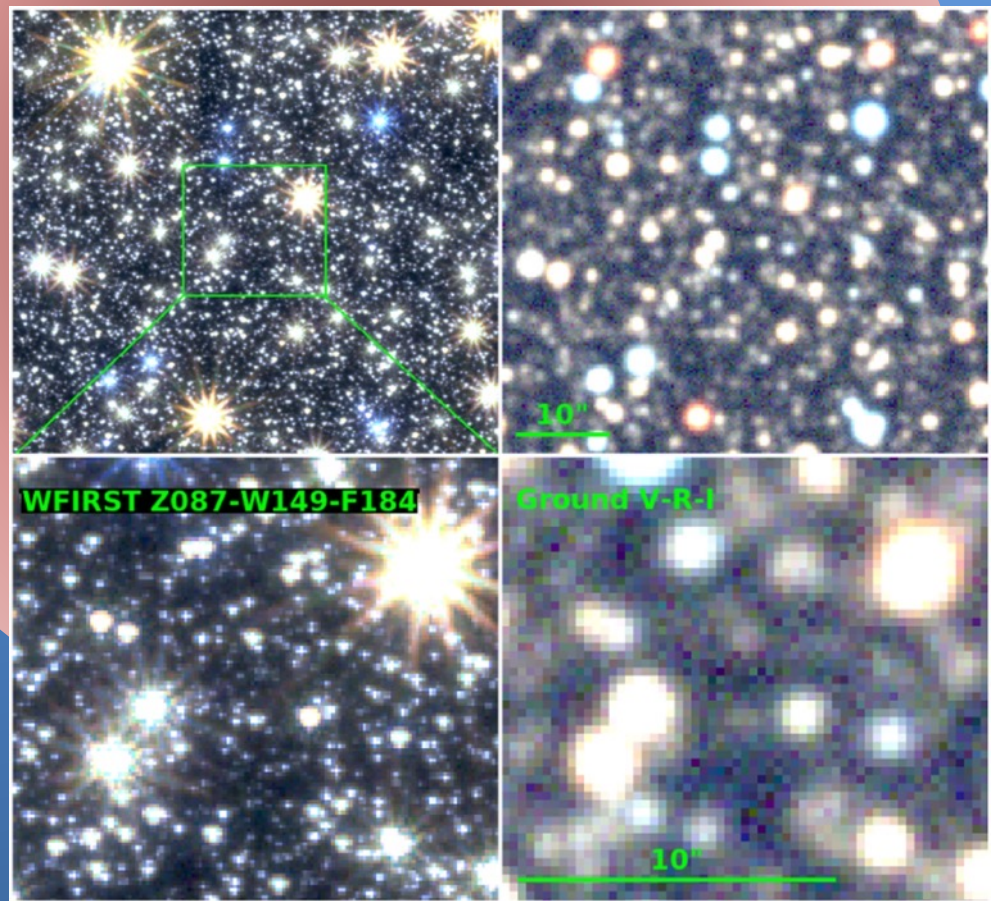
Medford et al. (2020)

Major gains possible with joint processing

Relative Rubin Resolution

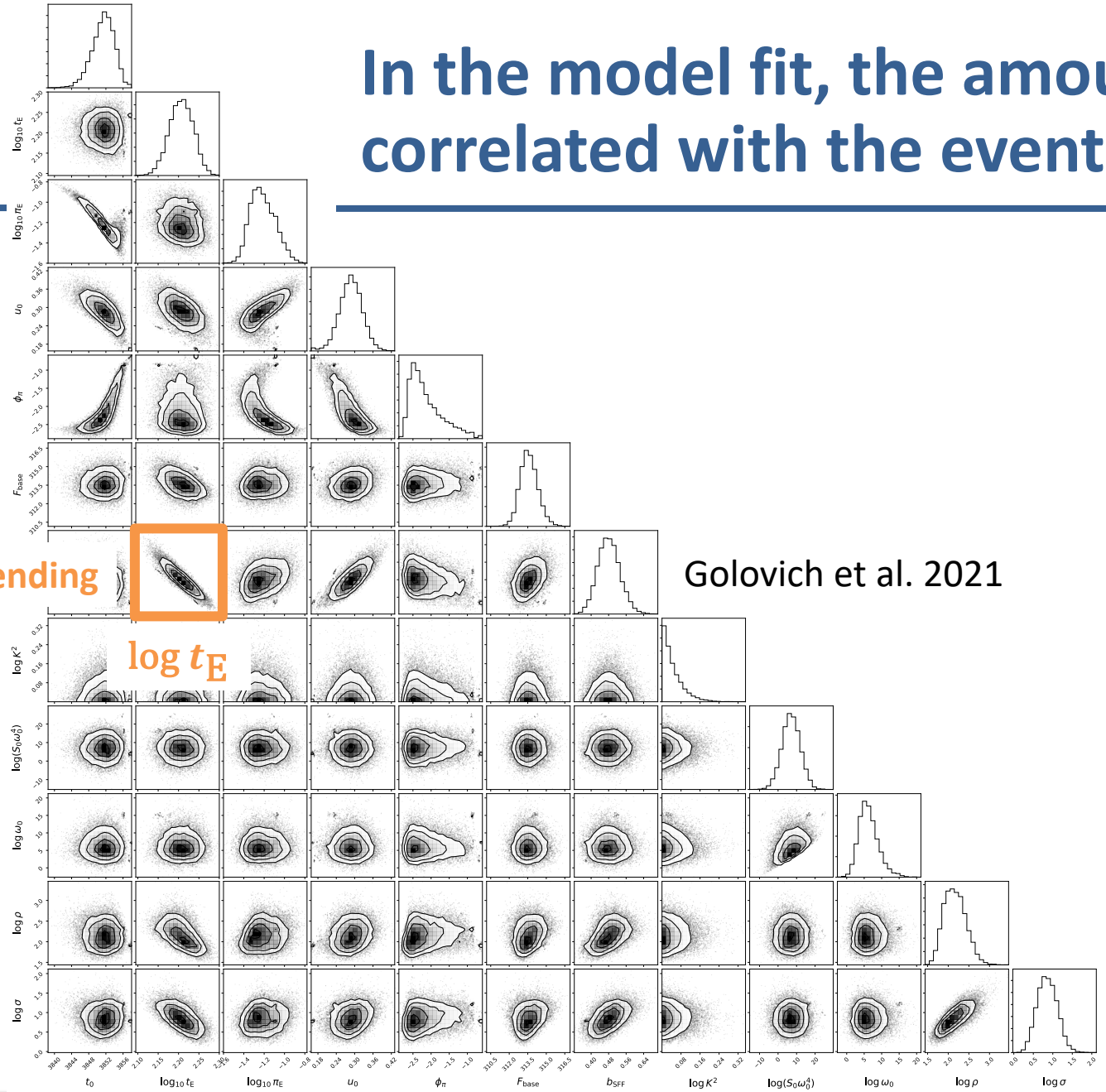
Relative Roman Resolution



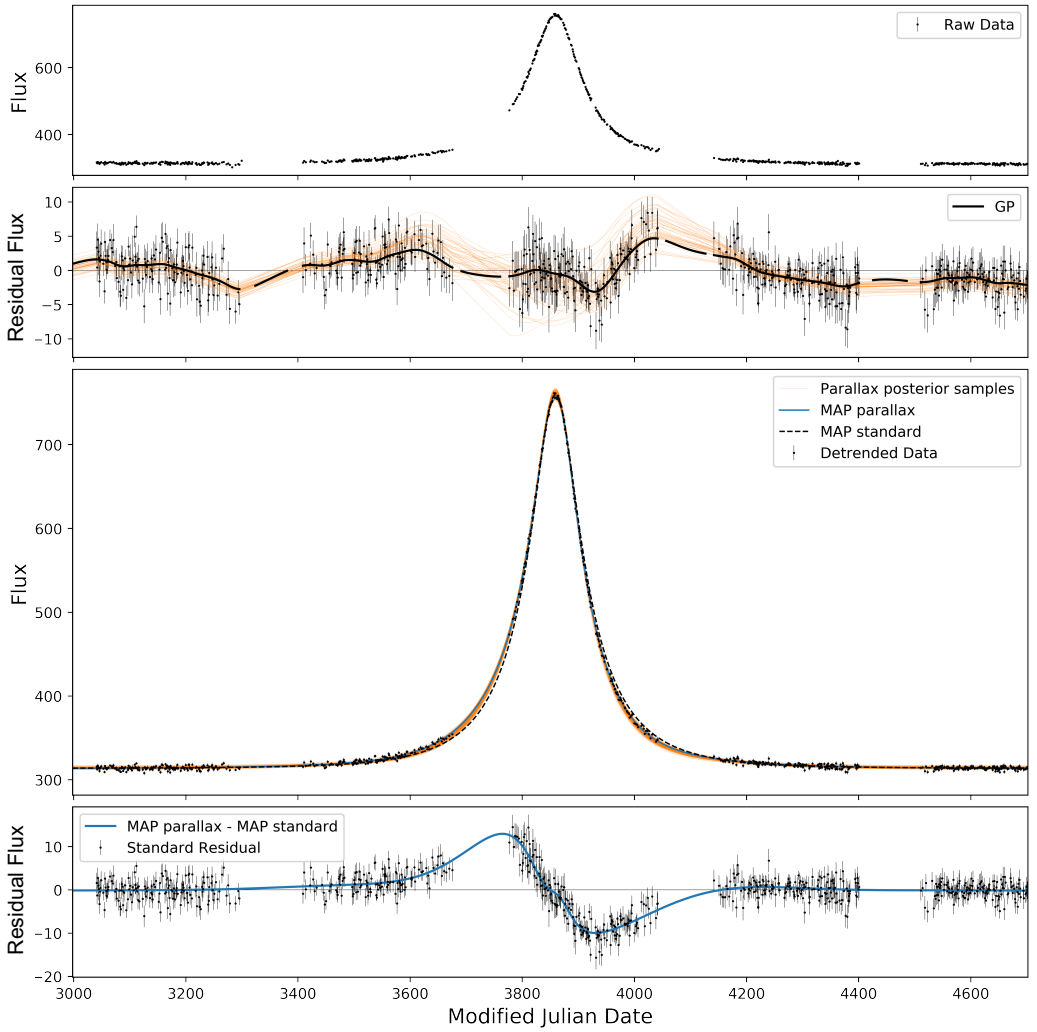


Penny et al. 2019

In the model fit, the amount of blending is highly correlated with the event duration



Golovich et al. 2021



Joint pixel-level process is the correct way to fuse surveys, but outstanding challenges remain

Snowmass2021 - Letter of Interest

Joint pixel-level processing of WFIRST, Euclid, LSST, and SPHEREx

Thematic Areas: (check all that apply ☐/■)

☐ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
☐ (Other) *[Please specify frontier/topical group]*

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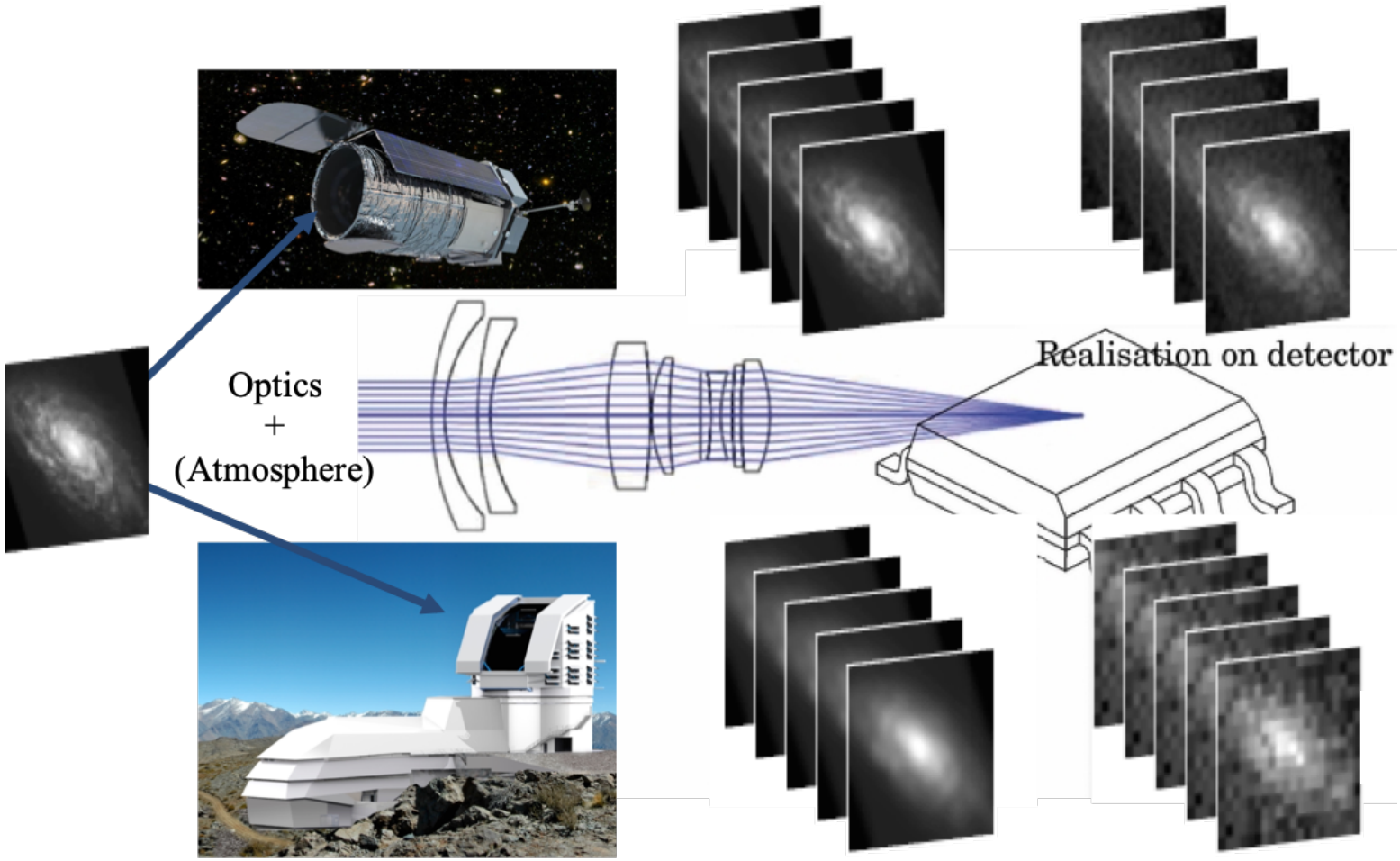
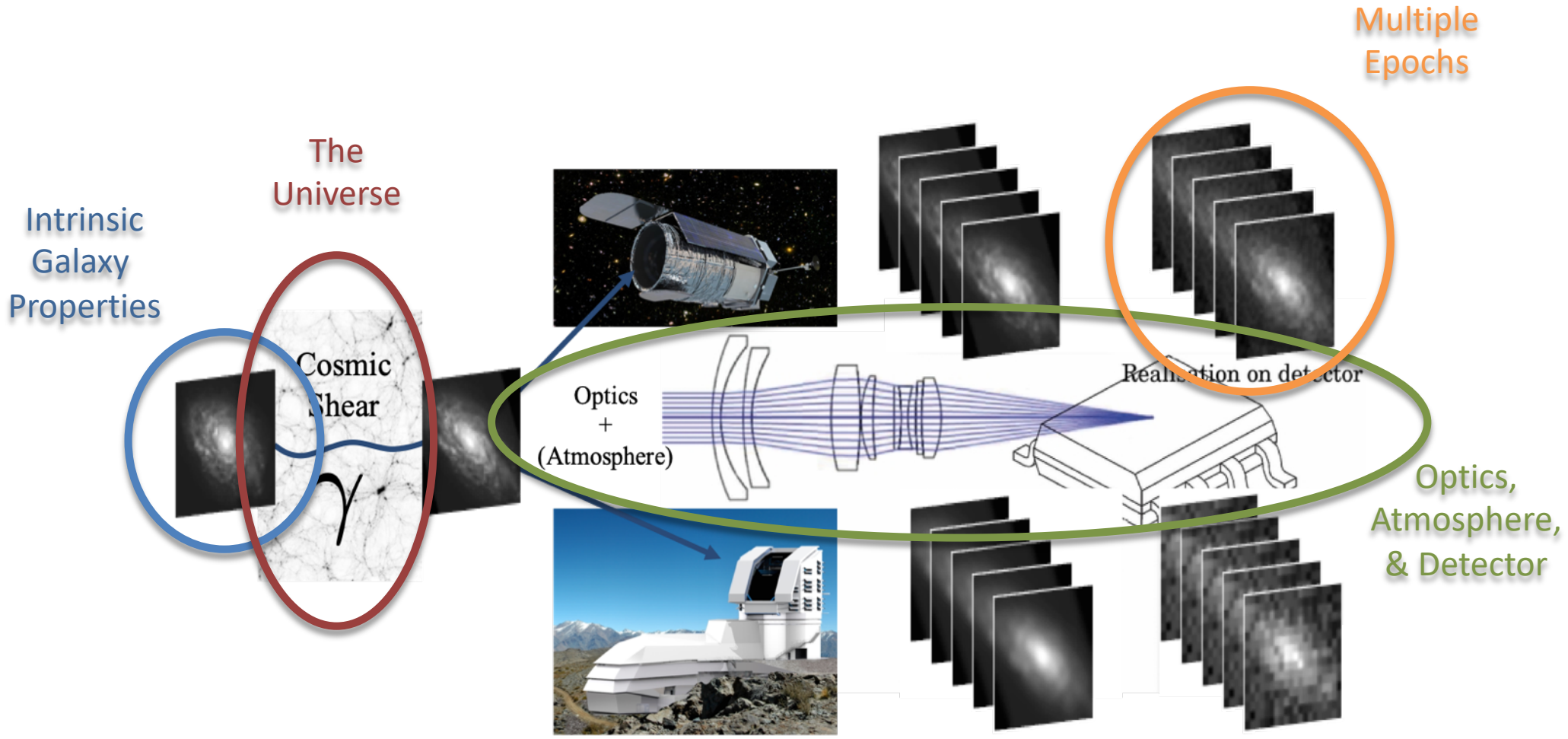
- Scaling to hundreds of images
- Handling dramatically different resolutions
- Handling very blended fields

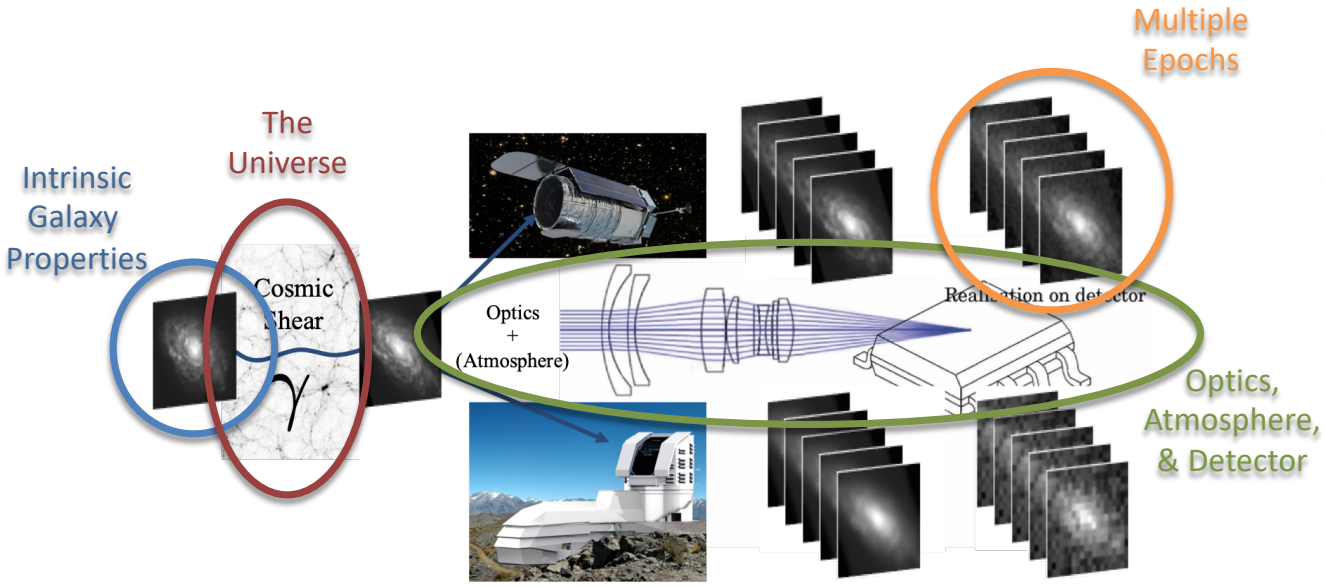
Fusing multi-sensor data



Learning a lesson from properly fusing data cosmic shear data

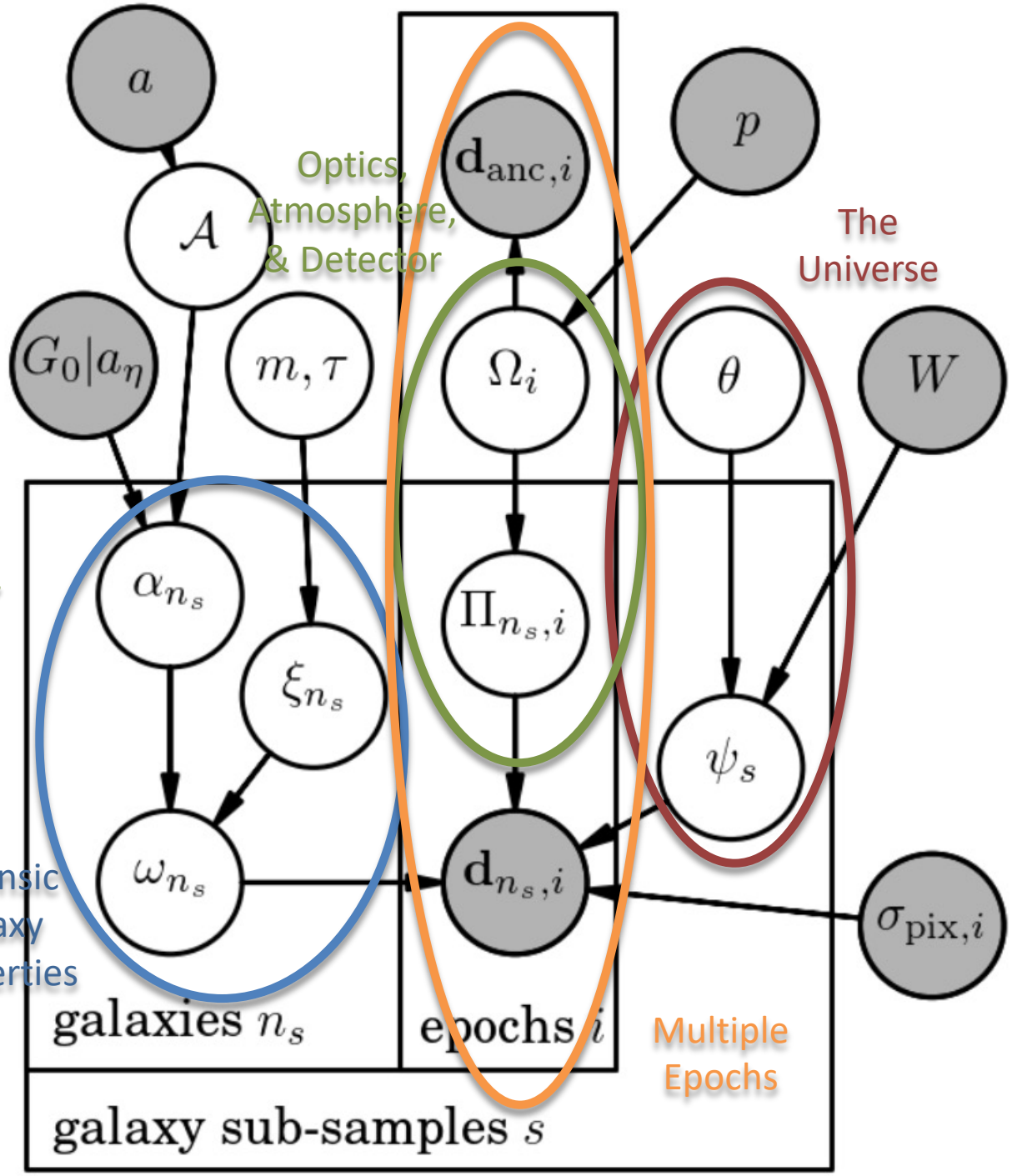


Hierarchical Bayesian Inference



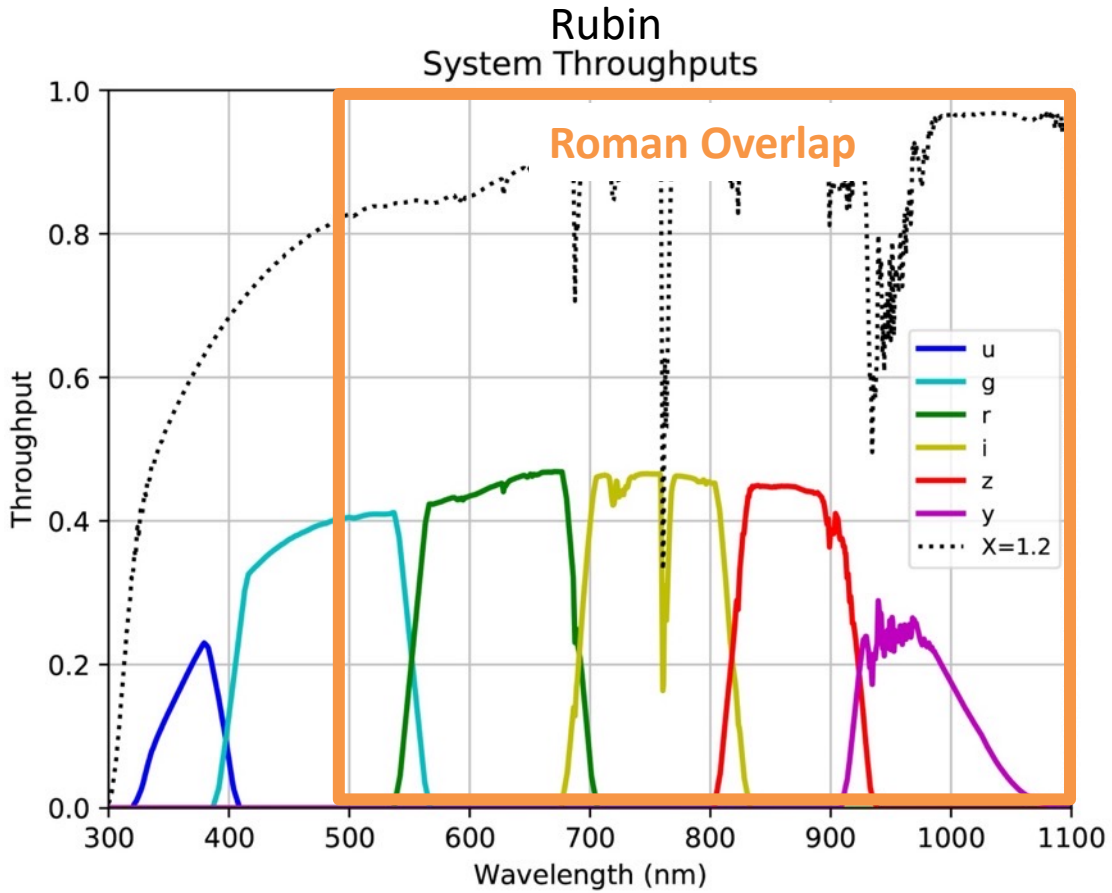
Could simplify process by:

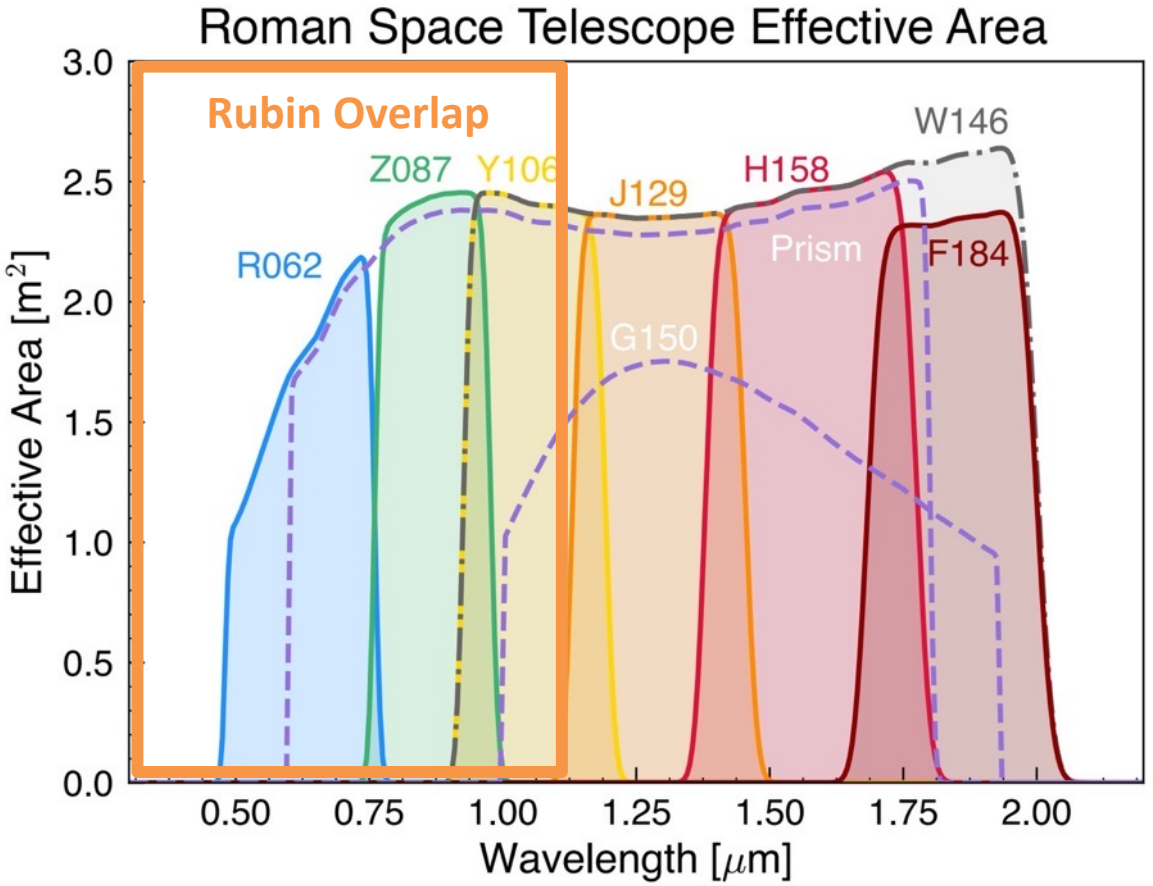
- Treating Roman results as a prior for the ground-based data
- Just performing analysis for detected microlensing events



Schneider et al. 2015

More, but infrequent, observations in overlapping bands can improve the joint survey modeling





Summary

- Roman + Rubin + others will observe and characterize $\mathcal{O}(100-1000)$ black holes in the 2020s
- Potentially solving one of the greatest black hole mysteries of our day
- With slight modifications to each survey, they can be optimized for complementarity
  - Coordinating spatio-temporal coverage
  - Occasionally observing in overlapping bands and time