UKIRT Microlensing Survey as a Pathfinder for Roman

UKIRT Microlensing Team

Chas Beichman, Geoffrey Bryden, Sebastiano Calchi Novati, Selina Chu, Scott Gaudi, Calen Henderson,

Adrian Hernandez, Savannah Jacklin, Samson Johnson,

David Nataf, Matthew Penny, Radek Poleski,

Yossi Shvartzvald, Kiri Wagstaff, Jennifer Yee

Near-IR Microlensing

I-band microlensing surveys

OGLE

MOA

KMTNet

near-IR microlensing surveys

UKIRT

3.8m NIR telescope @ Mauna Kea

Roman

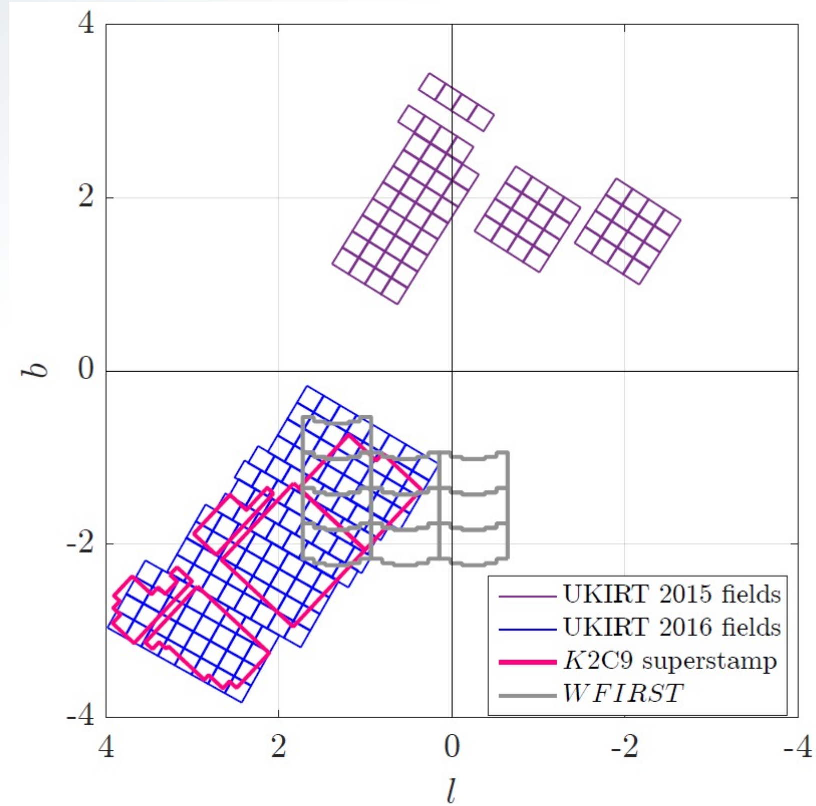
UKIRT 2015-2016 pilot studies

2015 survey for *Spitzer*:

- Area: 3.4 deg^2
- Duration: 39 nights
- Cadence: 5 epochs/night
- Total epochs per field: ~145
- Filter: *H*

2016 survey for *K2C9*:

- Area: 6.0 deg^2
- Duration: 91 nights
- Cadence: 2-3 epochs/night
- Total epochs per field: ~160
- Filter: *H*

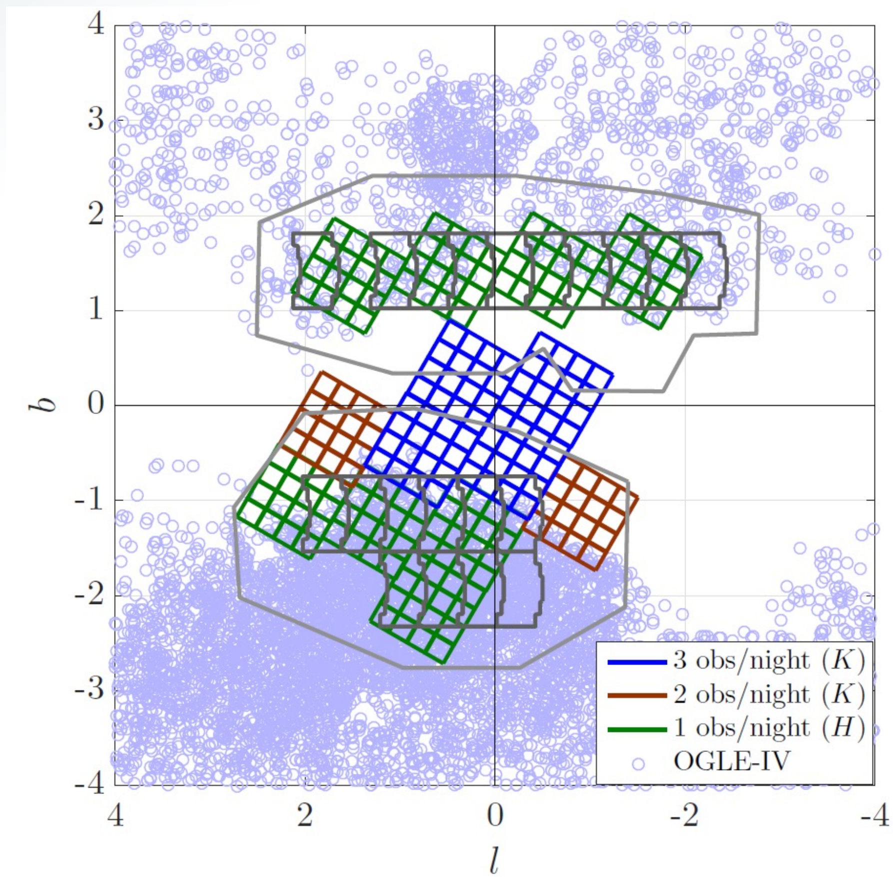


Shvartzvald et al. 2017

UKIRT 2017-2019 microlensing survey

2017-2019 survey for Roman:

- Area: 10.5 deg^2
- ~20 million lightcurves
- Duration: ~4 months / season
- Cadence: 1-3 epochs / night
- Filters: *H* & *K*



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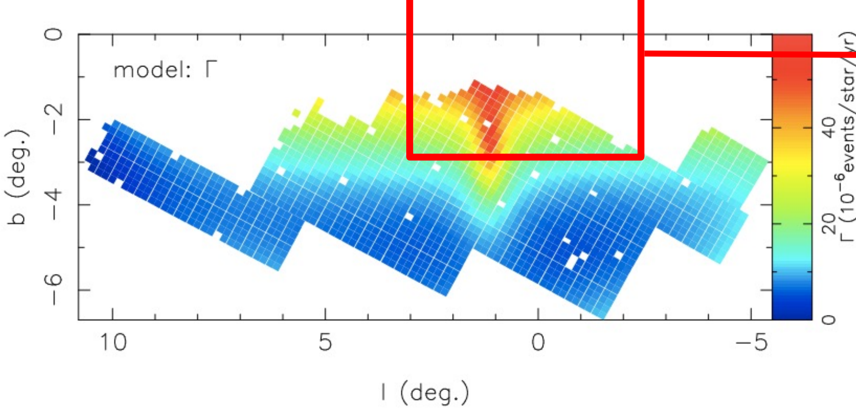
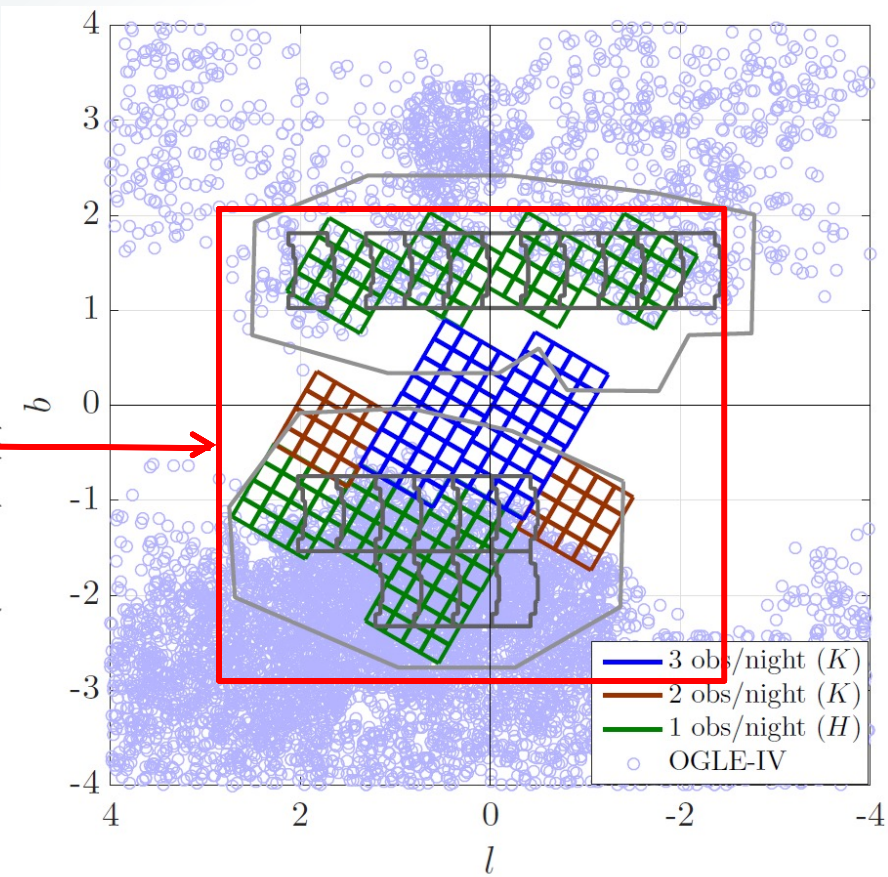


Sumi & Penny 2016



Machine-Learning Event Detection

The motivation for a machine-learning classification scheme is two-fold:

Goal 1: Efficiently detect microlensing events

While our UKIRT microlensing survey is small enough that by-eye evaluation is feasible, Roman will have an order of magnitude more events; the larger the dataset, the more potential for time saved, particularly for real-time analysis of an ongoing survey.

Goal 2: Enable robust detection statistics

Machine-learning offers a consistent, fast method for classifying an arbitrarily large set of lightcurves – either real or simulated – such that detection efficiency can be rigorously quantified.

Lightcurve Inspection

Even with machine learning, we need to start with some by-eye analysis. The computer has to learn from the labeled examples we provide.

- We start with an event finder similar to KMT (Kim et al. 2018), based on a 2-D (t_0, t_{eff}) grid search
- **Manual UKIRT Lightcurve Evaluator (MULE)** – a python-based GUI to assist with the by-eye vetting of lightcurves

We look at everything with $\Delta\chi^2 > 500$.

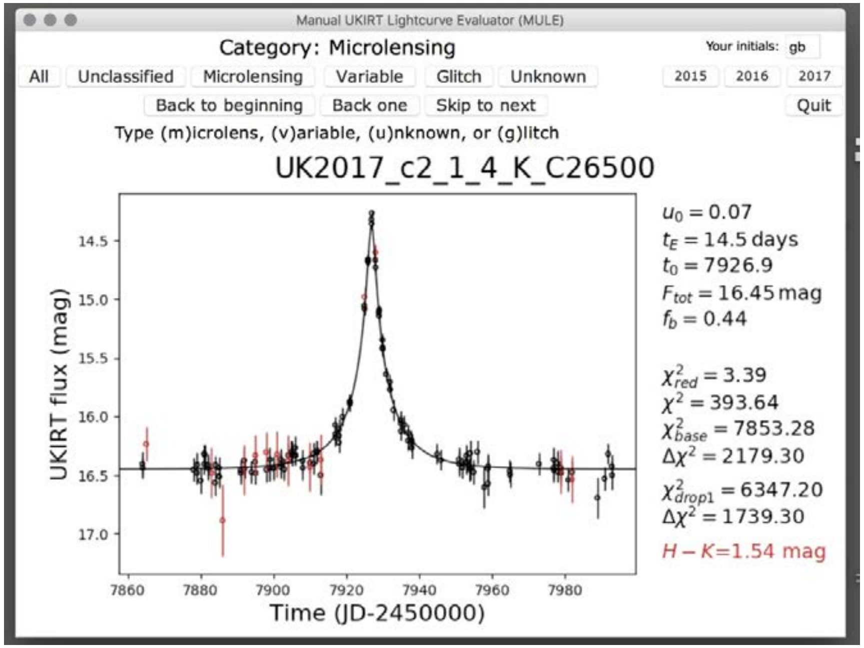
2015: 23 events (out of 562)

2016: 65 events (out of 844)

2017: 191 events (out of 2852)

2018: 83 events (out of 843)

2019: 133 events (out of 2576)

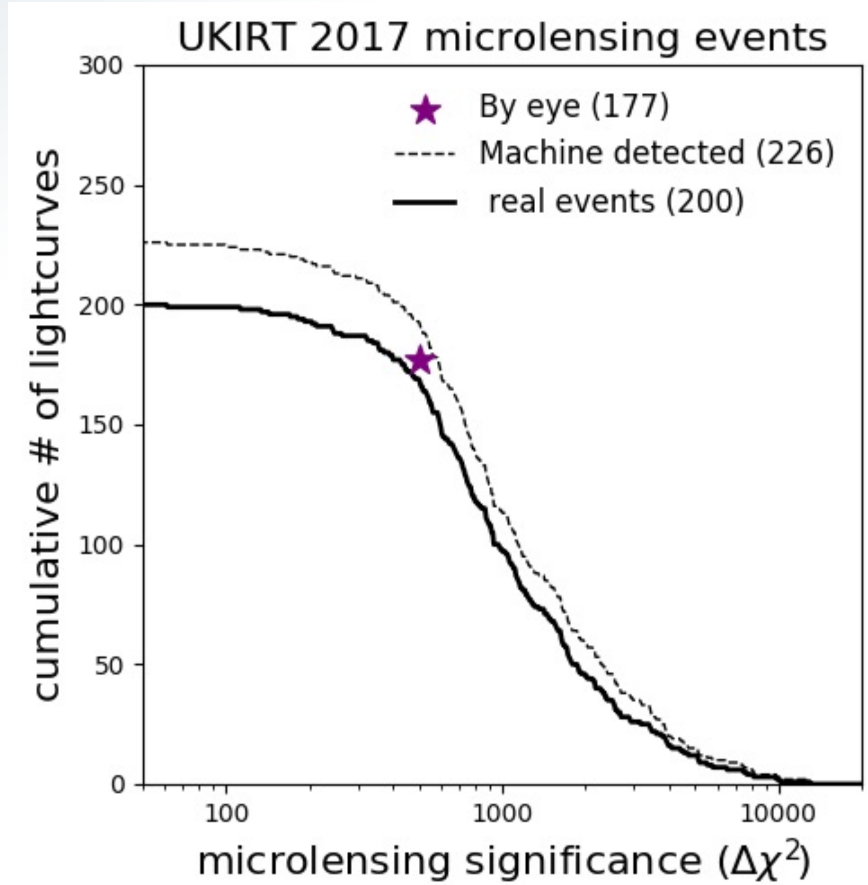


Machine Learning Classification

The UKIRT survey is small enough that by-eye analysis can identify most of the events.

Only a modest increase in the number of events detected:
495 by-eye events →
719 machine-learning events

Some of the original detections are missed by the machine learning scheme and there are some false detections (variable stars that look similar to microlensing events).
Overall false positive/
false negative rates are ~5%.



Detection Efficiency

Detection efficiency is calculated via simulated event injection/recovery.

- Inject events using PSF templates from PSFEx
- Run through full pipeline, including machine-learning event detection
- Repeat for many stars in many fields, covering parameter space

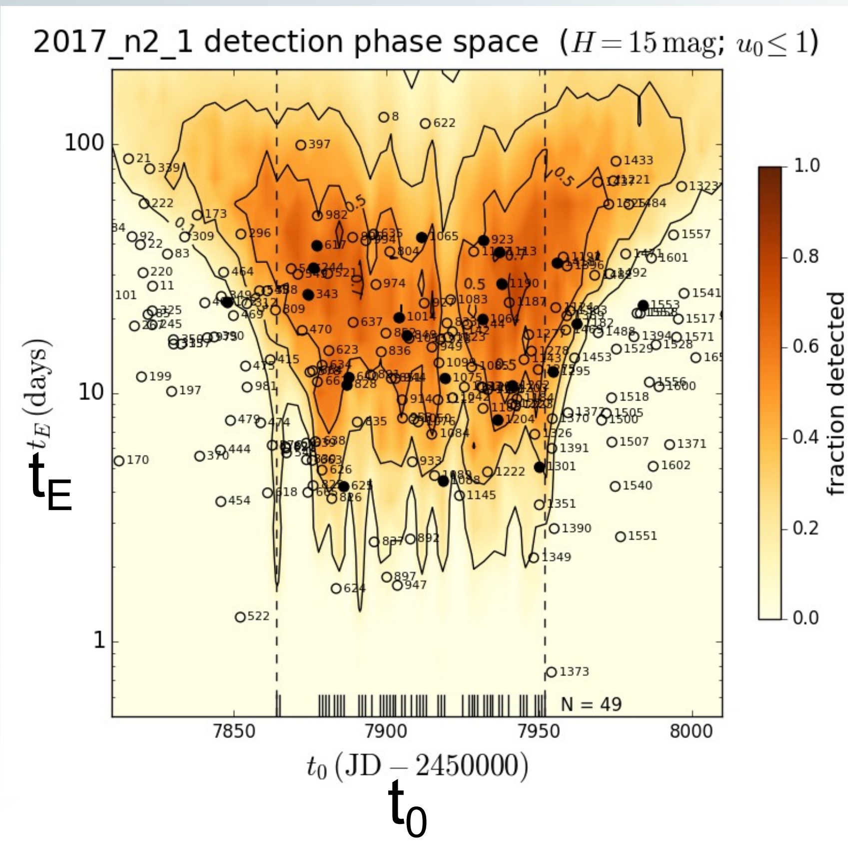
Note that detection rates cannot be calculated via by-eye selection. Detection efficiency must be calculated based on some well-defined selection criteria – either machine learning or strict cuts.

Traditionally, to avoid contamination by non-microlensing events, strict cuts are imposed that exclude many real events (e.g. Sumi+ 2011,2013 statistical sample contains 474 out of >1000 MOA events). Machine learning offers a dramatic improvement over simple deterministic cuts. Many more events are included, while still maintaining high precision.

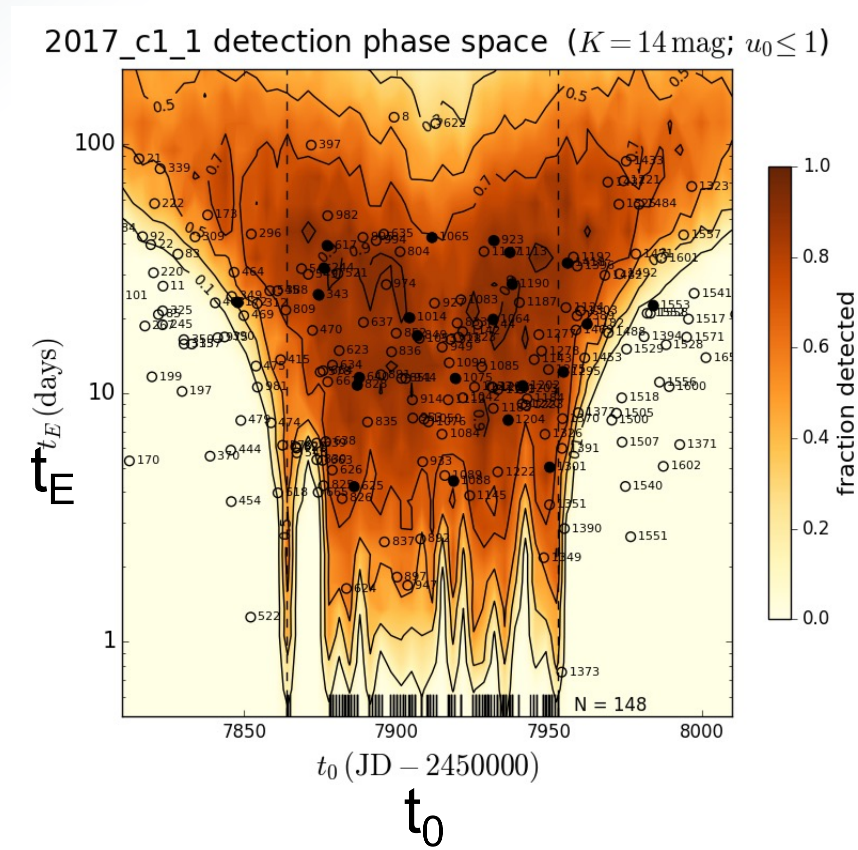
Detection Efficiency

The detection efficiency is higher in the central fields where the observing cadence is higher (3x/day vs 1x/day).

<u>Northern fields</u>



<u>Central fields</u>



Microlensing Events: UKIRT vs OGLE

<u>UKIRT summary</u>

2015: 15 events

2016: 80 events

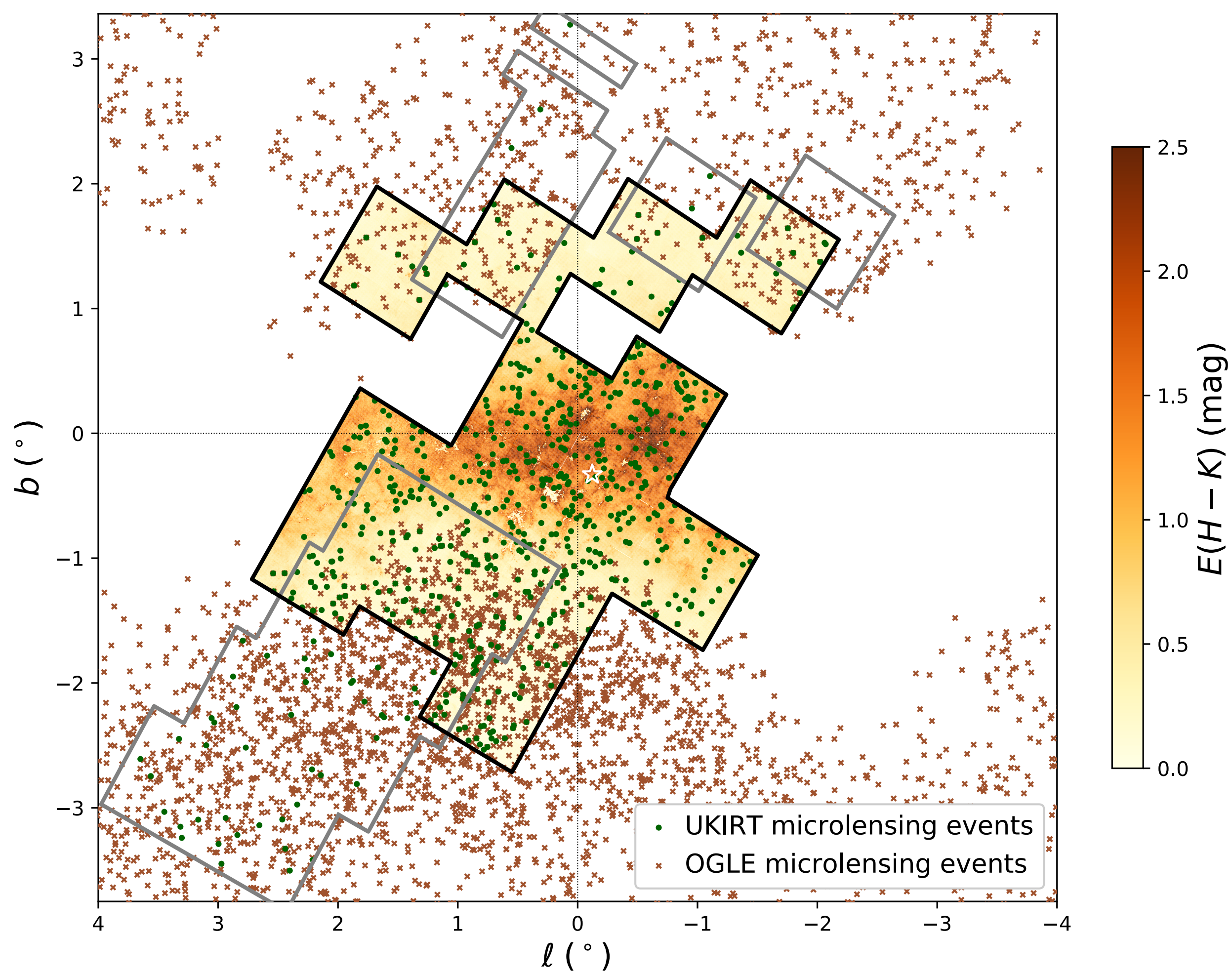
2017: 292 events

2018: 118 events

2019: 214 events

Total: 719 events

(OGLE has ~2000 events per year)



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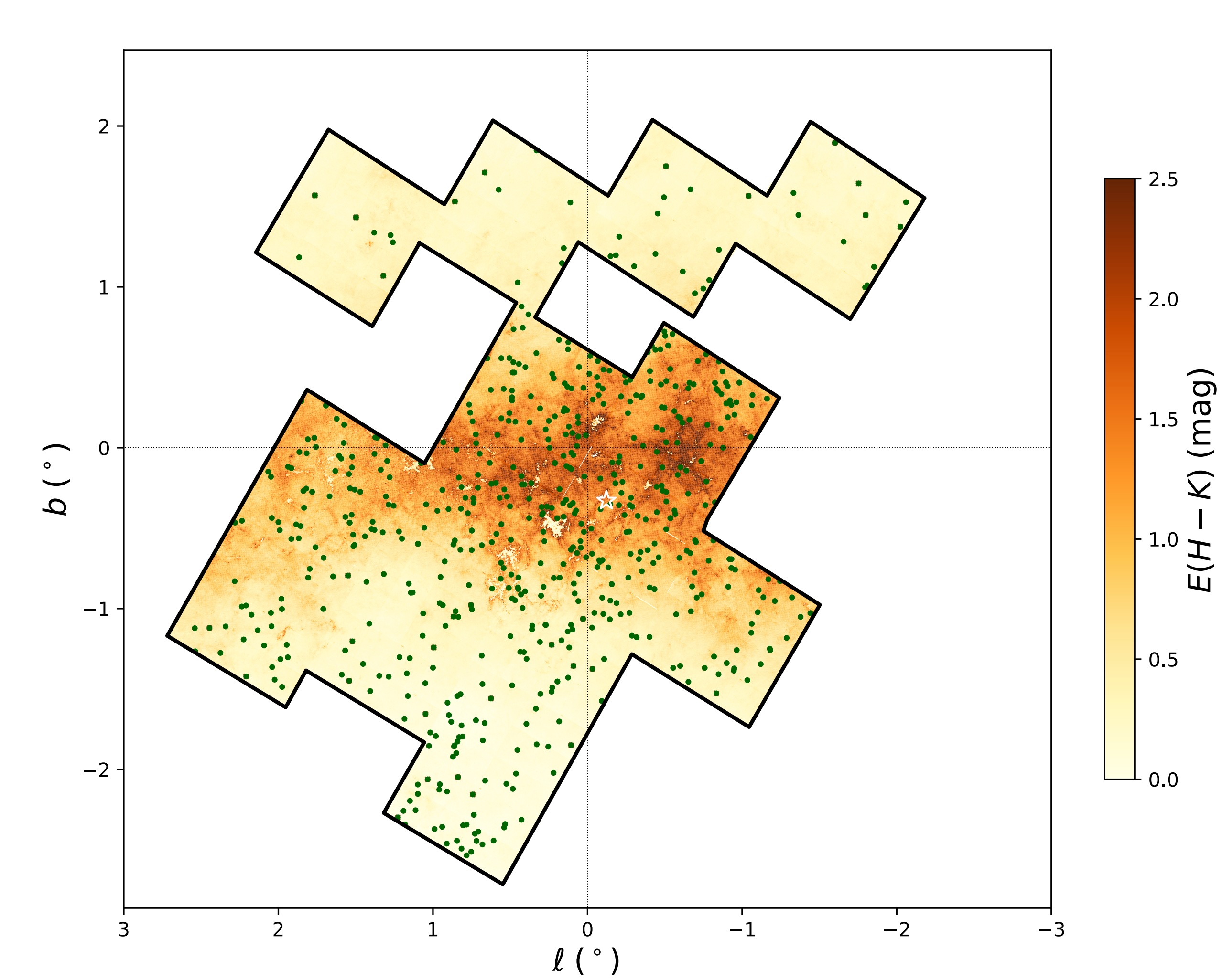
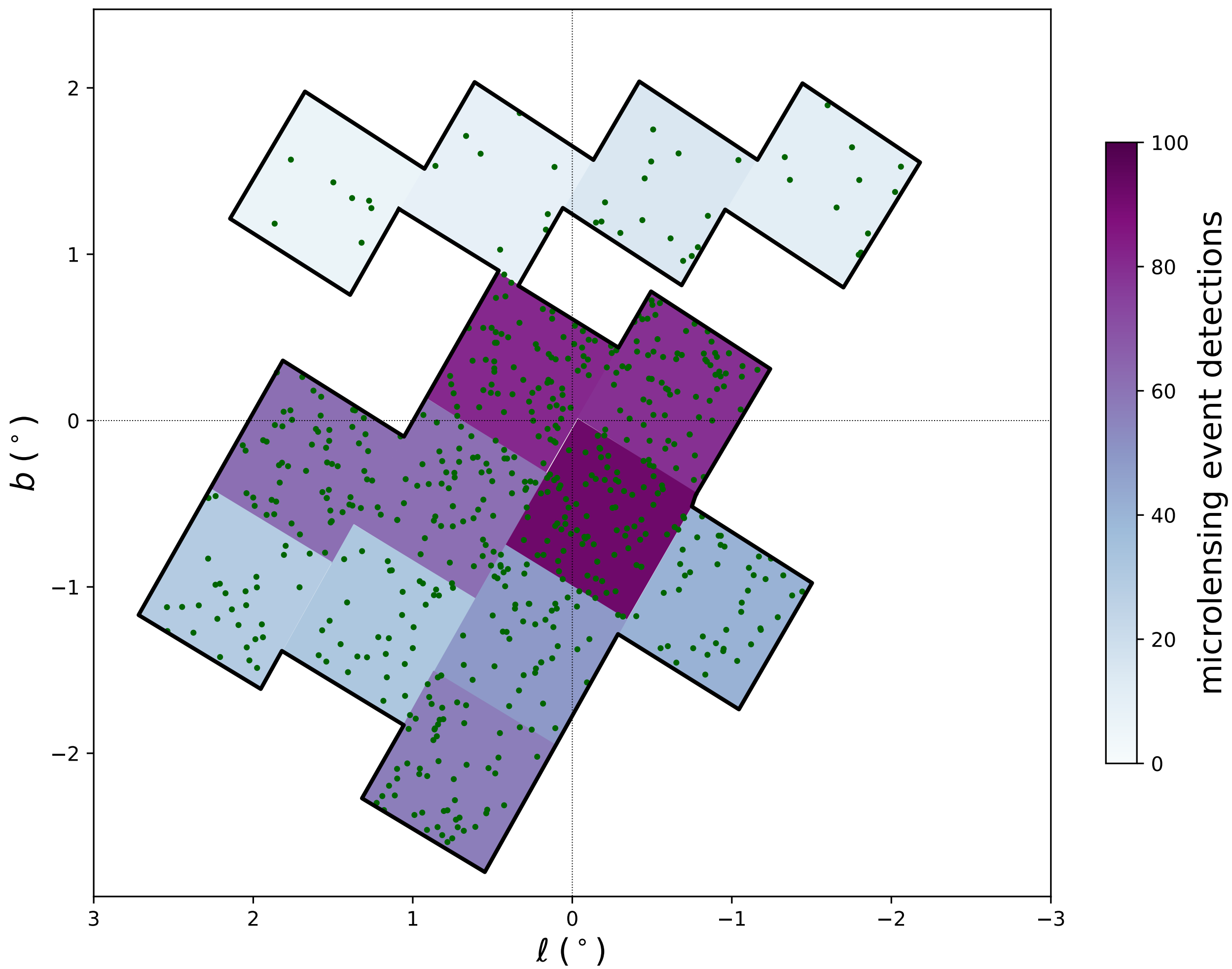


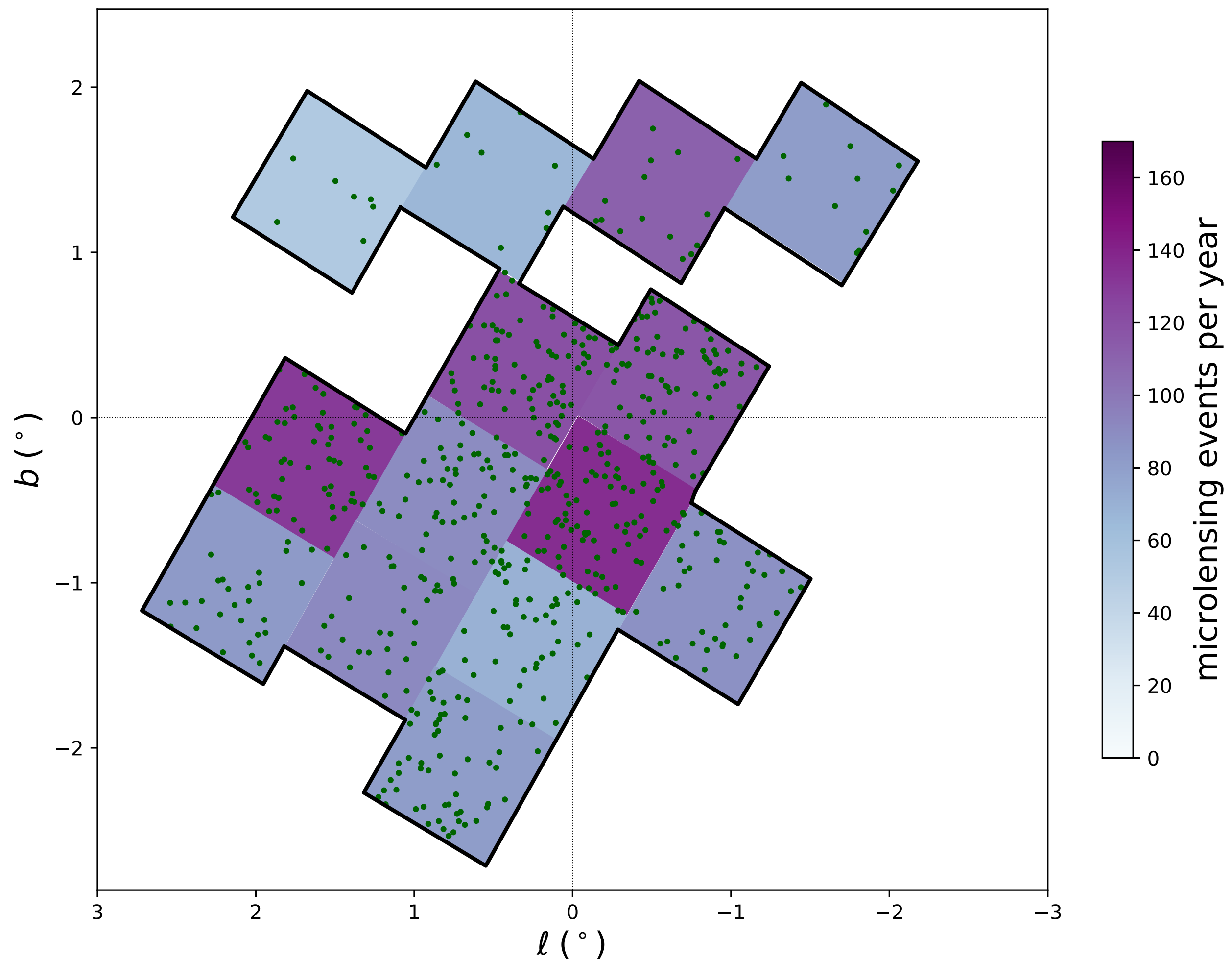
Microlensing Events: Raw Map

The north had lower cadence and only 1 year of observations, resulting in less detections.



Microlensing Events: Corrected Map

After correcting for this, the north has a similar detection rate as the south.



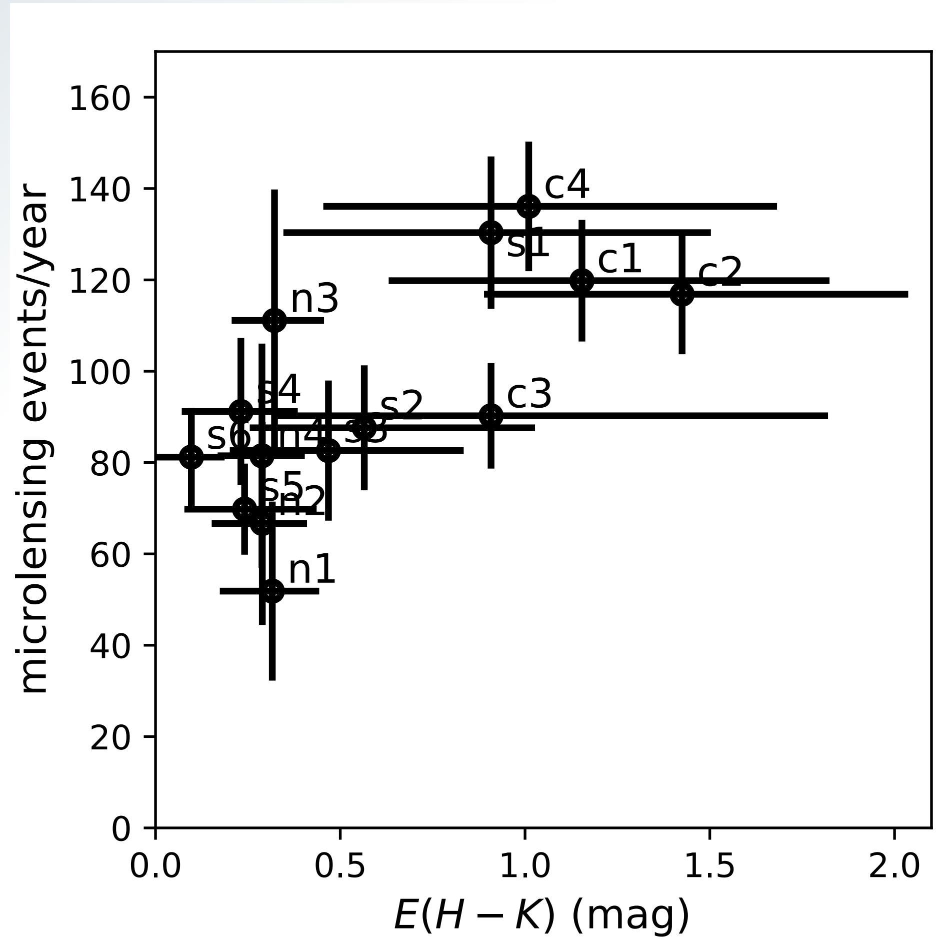
Roman Target Field Selection

UKIRT results provide an input for survey yield optimization (Penny/Johnson talk).

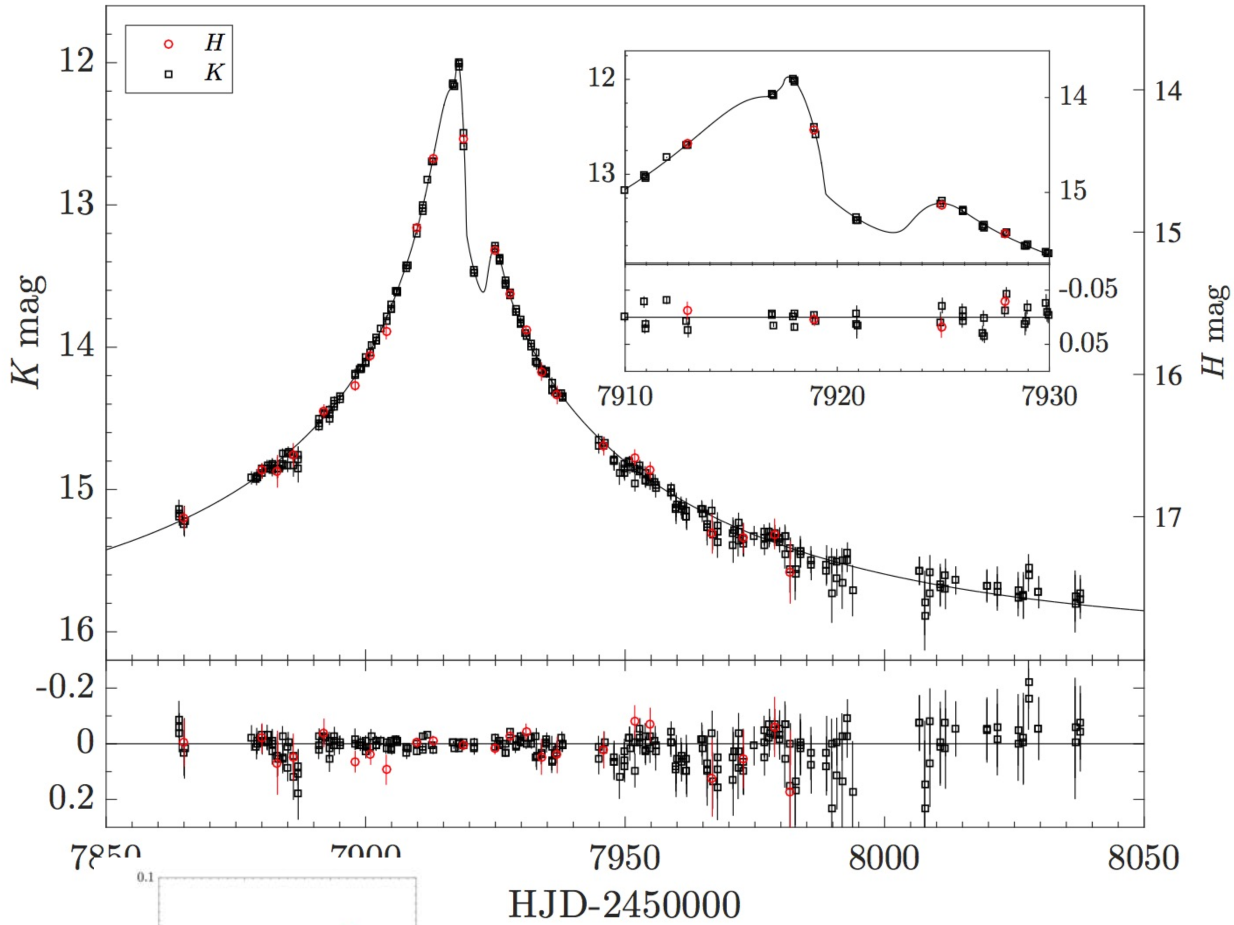
Roman target field selection must consider several factors:

- microlensing event rate
- extinction and, in particular, differential extinction
- overlap with ground-based surveys (optical & near-IR)
- continuity / slew minimization

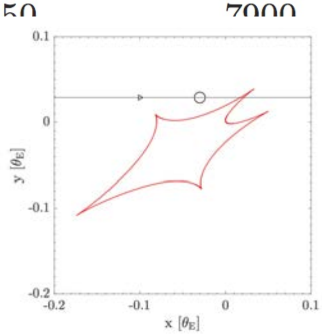
Bottom line:
Central fields have a higher microlensing event rate, but they also have more extinction.



UKIRT-2017-BLG-001b



Parameter	Full dataset
t_0 [HJD']	7916.235 ± 0.018
u_0	$0.0292^{+0.0032}_{-0.0021}$
t_E [d]	$103.9^{+6.9}_{-8.8}$
$\rho[10^{-3}]$	$6.38^{+0.63}_{-0.45}$
α [rad]	$3.7004^{+0.0069}_{-0.0061}$
s	$1.0325^{+0.0029}_{-0.0032}$
q $[10^{-3}]$	$1.44^{+0.15}_{-0.10}$
K_s	16.09 ± 0.09
f_b	$0.26^{+0.21}_{-0.29}$
$(H-K)_s$	1.810 ± 0.003
$t_{\rm eff}$ [d]	3.041 ± 0.032
t_* [d]	0.6624 ± 0.0078
qt_E [d]	0.1498 ± 0.0031
f_{lim}	199.2 ± 1.2

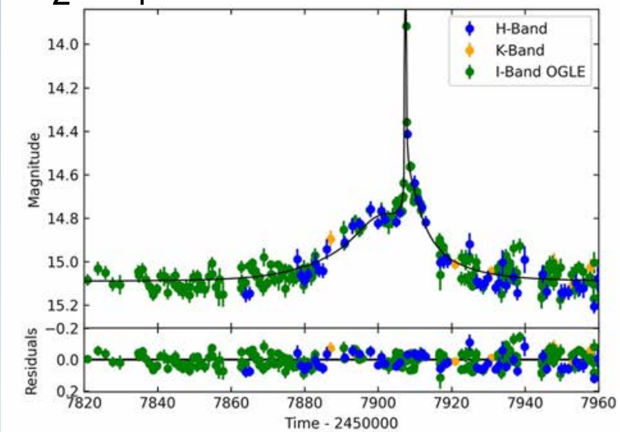


Shvartzvald et al. 2018

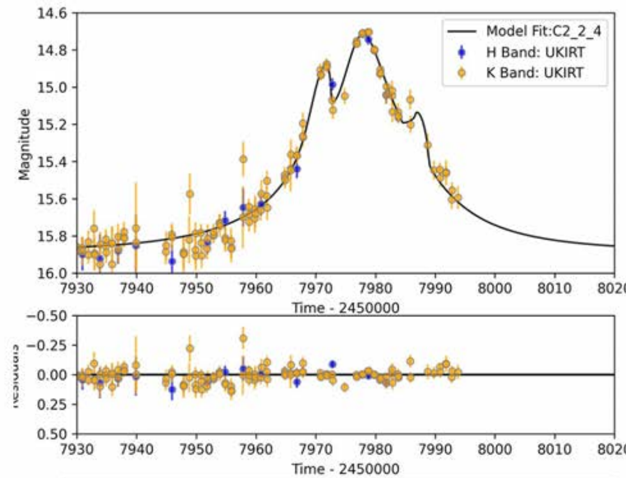
M_1 $[M_\odot]$	$0.81^{+0.31}_{-0.34}$
M_2 $[M_J]$	$1.22^{+0.48}_{-0.51}$
$r_\perp$ [AU]	$3.24^{+0.83}_{-0.91}$
D_L [kpc]	$5.4^{+1.4}_{-1.7}$

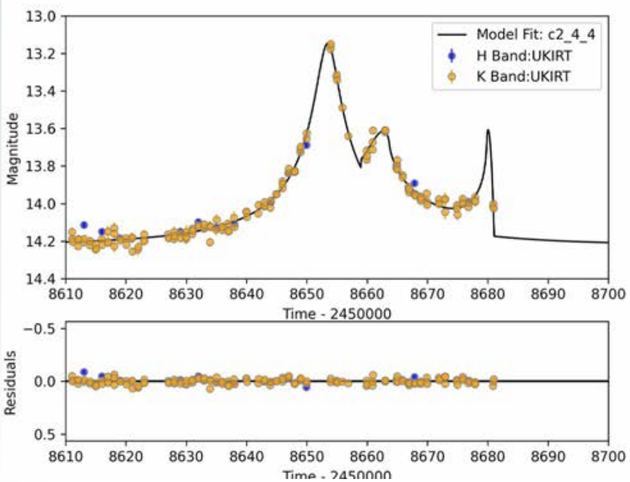
More Binaries/Brown Dwarfs/Planets

$M_2/M_1 = 0.21 \pm 0.02$



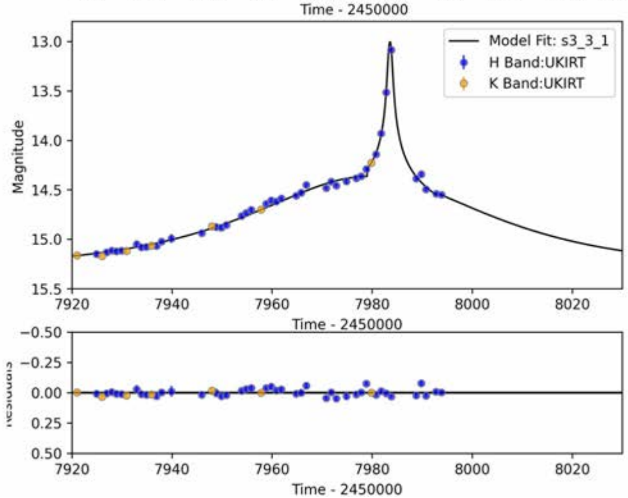
$M_2/M_1 = 0.035 \pm 0.006$





$M_2/M_1 = 0.069 \pm 0.005$

$M_2/M_1 = 0.87 \pm 0.12$



credit: MulensModel (Poleski & Yee)

Adrian Hernandez
Cal. State. Univ. Los Angeles

Summary

The UKIRT microlensing survey is serving as a precursor for Roman by

- mapping the microlensing event rate
- identifying regions with high differential extinction
- developing analysis tools (e.g. machine learning)
- enabling hands-on experience for new microlensers

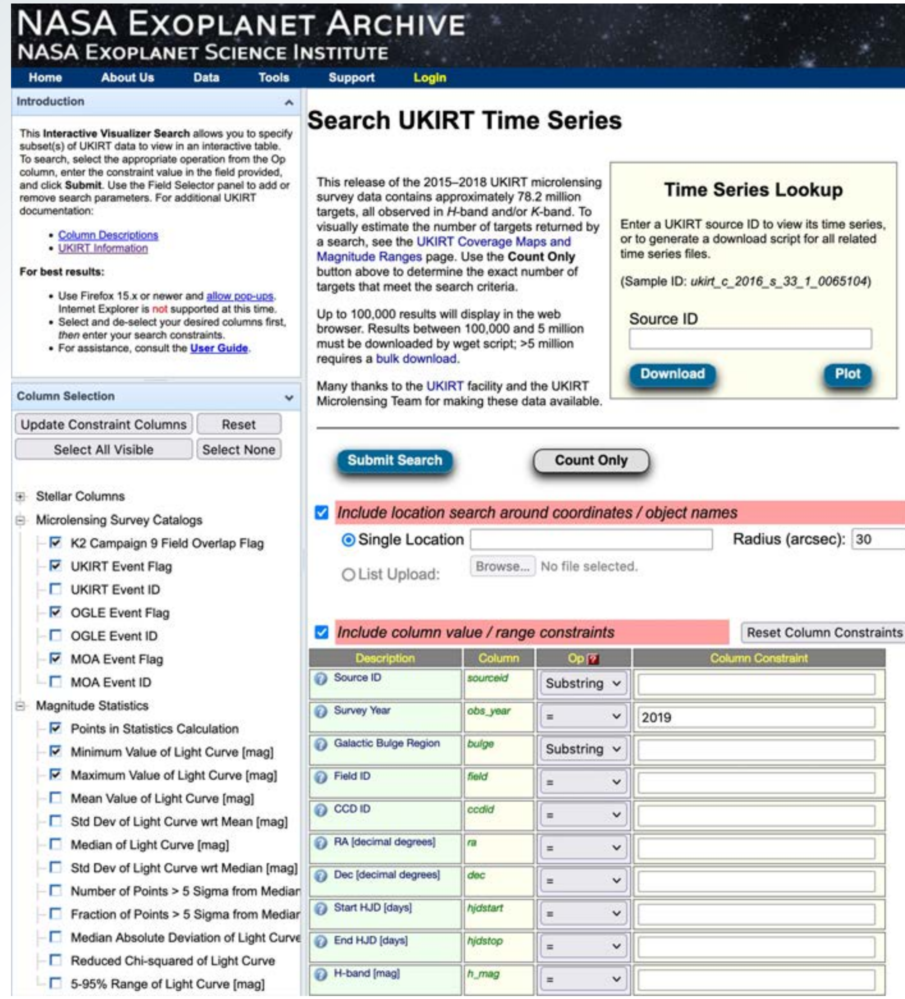
Beyond microlensing, the survey data is available for

- variable stars
- outlier events
- extinction maps
- Galactic structure
- etc.

Data Access

Lightcurves are available online in the NASA Exoplanet Archive

- 78M independent lightcurves for 35M sources
- Archive tools for selection, sorting, visualization, etc.
- Flagging of known events
- Cross-matching with OGLE/MOA microlensing surveys



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