

UKIRT Microlensing Survey as a Pathfinder for Roman

UKIRT Microlensing Team

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Near-IR Microlensing

I-band microlensing surveys



OGLE



MOA



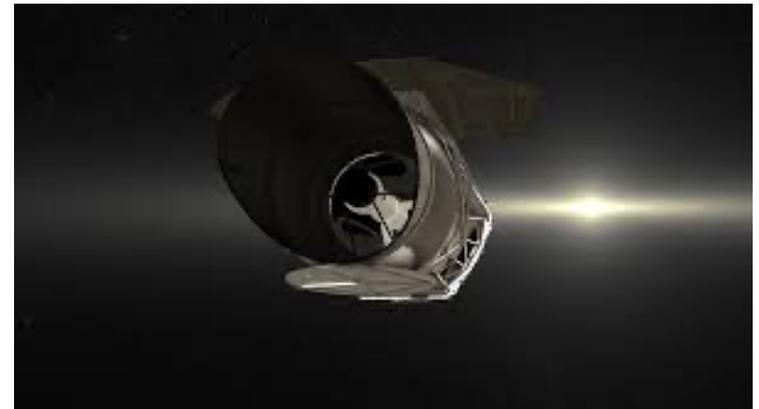
KMTNet

near-IR microlensing surveys



UKIRT

3.8m NIR telescope @ Mauna Kea



Roman

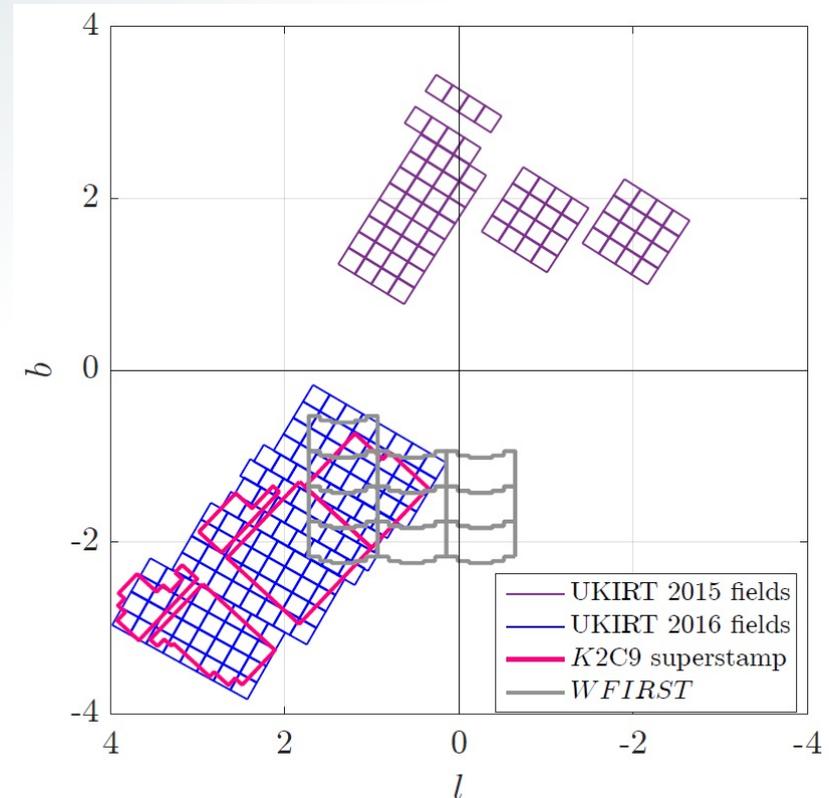
UKIRT 2015-2016 pilot studies

2015 survey for *Spitzer*:

- Area: 3.4 deg²
- Duration: 39 nights
- Cadence: 5 epochs/night
- Total epochs per field: ~145
- Filter: *H*

2016 survey for *K2C9*:

- Area: 6.0 deg²
- Duration: 91 nights
- Cadence: 2-3 epochs/night
- Total epochs per field: ~160
- Filter: *H*

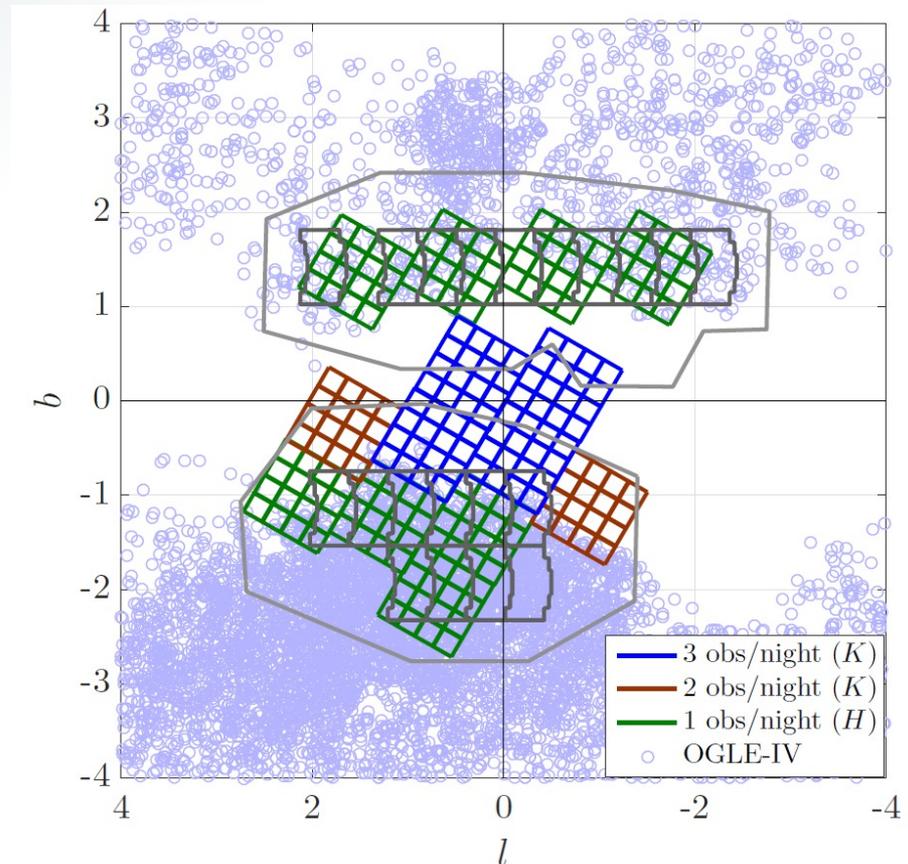


Shvartzvald et al. 2017

UKIRT 2017-2019 microlensing survey

2017-2019 survey for Roman:

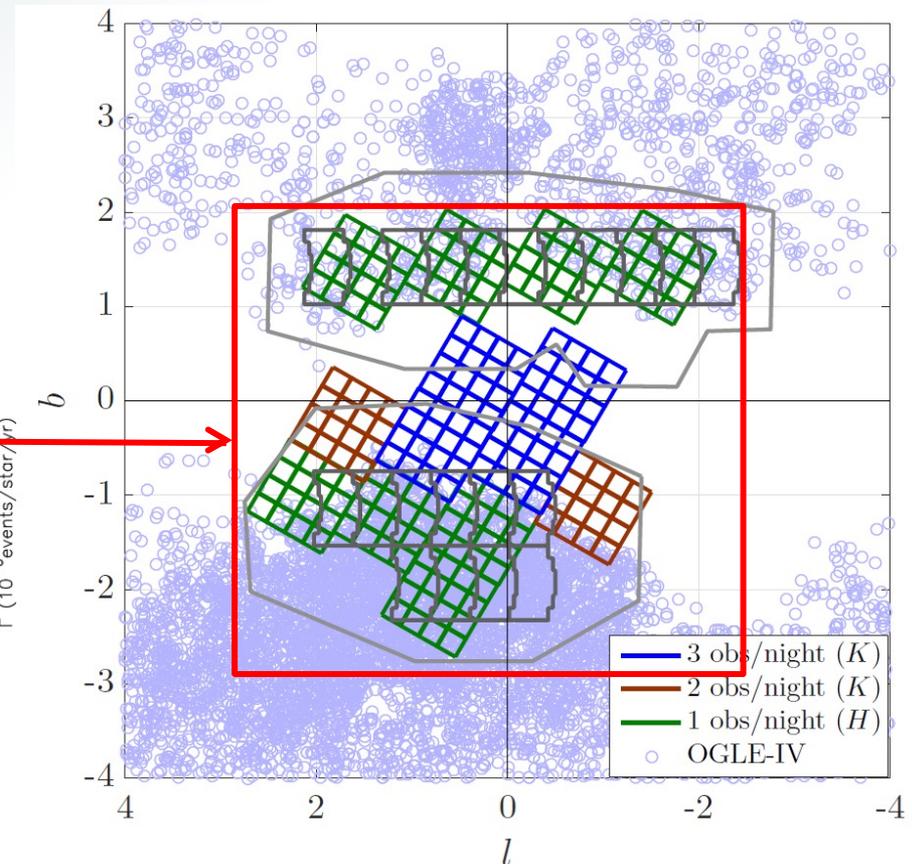
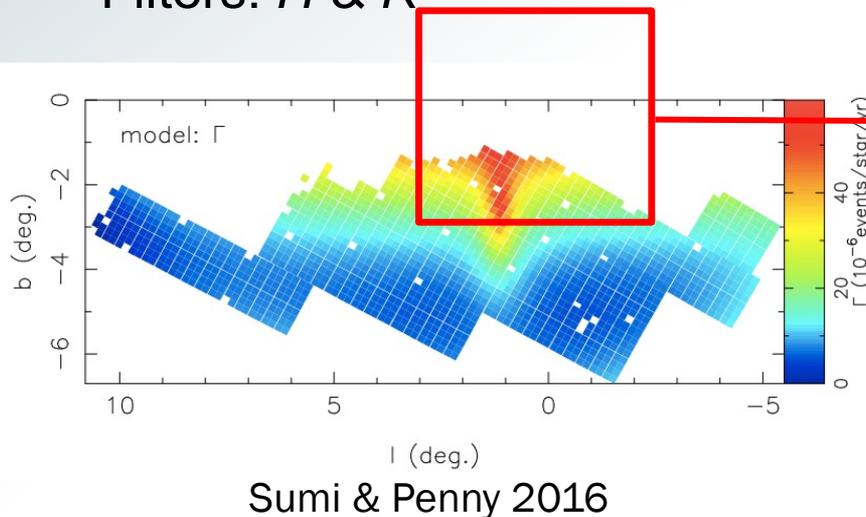
- Area: 10.5 deg²
- ~20 million lightcurves
- Duration: ~4 months / season
- Cadence: 1-3 epochs / night
- Filters: *H* & *K*



UKIRT 2017-2019 microlensing survey

2017-2019 survey for Roman:

- Area: 10.5 deg²
- ~20 million lightcurves
- Duration: ~4 months / season
- Cadence: 1-3 epochs / night
- Filters: *H* & *K*



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 $\Delta\chi^2 > 500$.

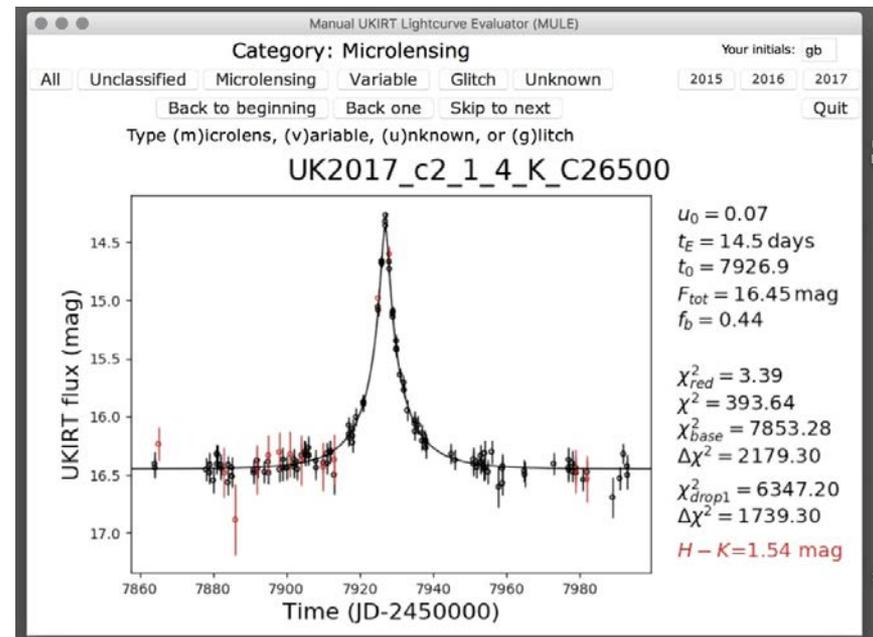
2015: 23 events (out of 562)

2016: 65 events (out of 844)

2017: 191 events (out of 2852)

2018: 83 events (out of 843)

2019: 133 events (out of 2576)

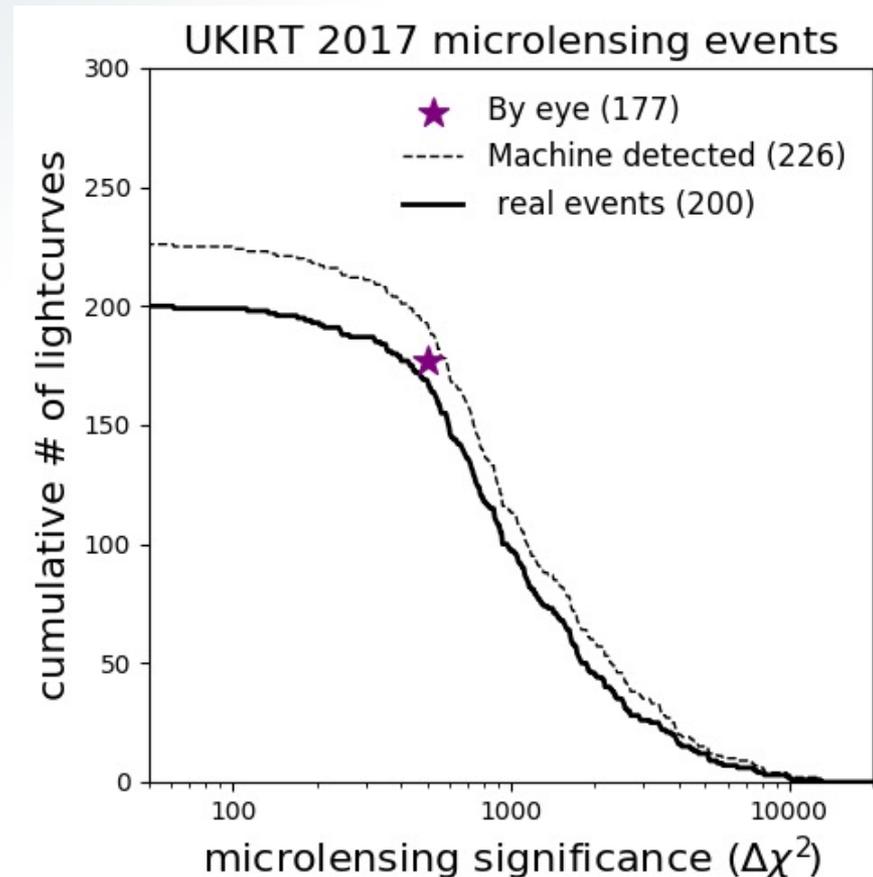


Machine Learning Classification

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.

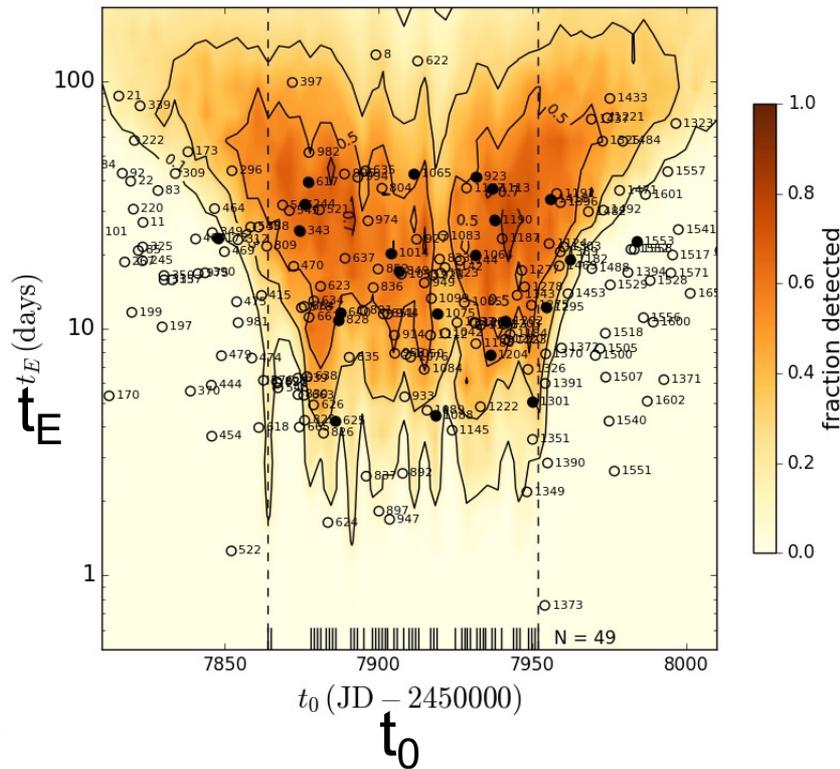
Traditionally, to avoid contamination by non-microlensing events, strict cuts are imposed that exclude many real events (e.g. Sumi+2011,2013 statistical sample contains 474 out of >1000 MOA events). Machine learning offers a dramatic improvement over simple deterministic cuts. Many more events are included,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

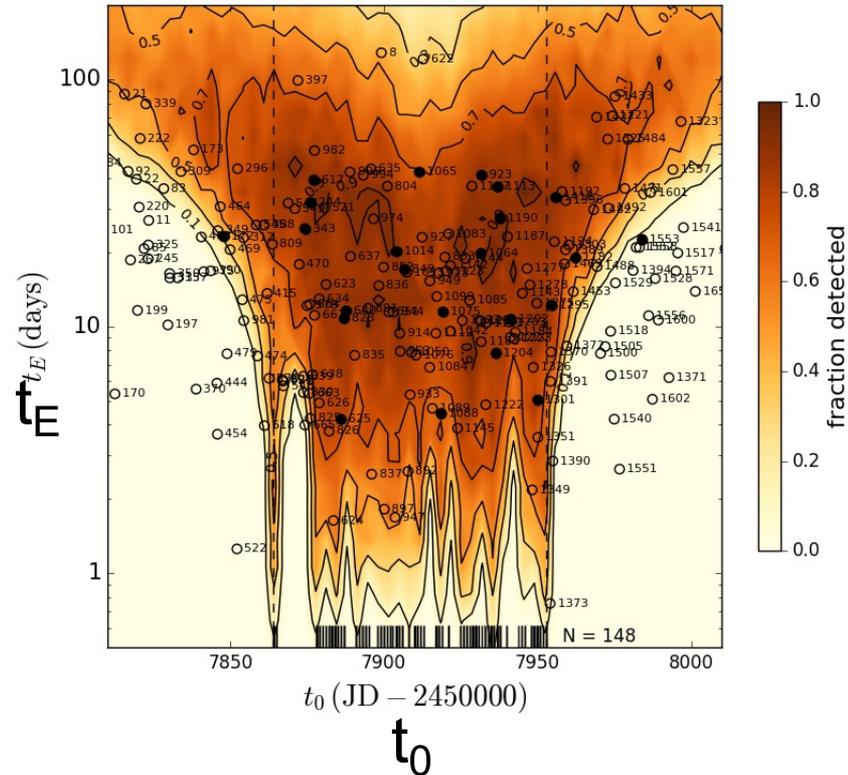
Northern fields

2017_n2_1 detection phase space ($H = 15$ mag; $u_0 \leq 1$)



Central fields

2017_c1_1 detection phase space ($K = 14$ mag; $u_0 \leq 1$)



Microlensing Events: UKIRT vs OGLE

UKIRT summary

2015: 15 events

2016: 80 events

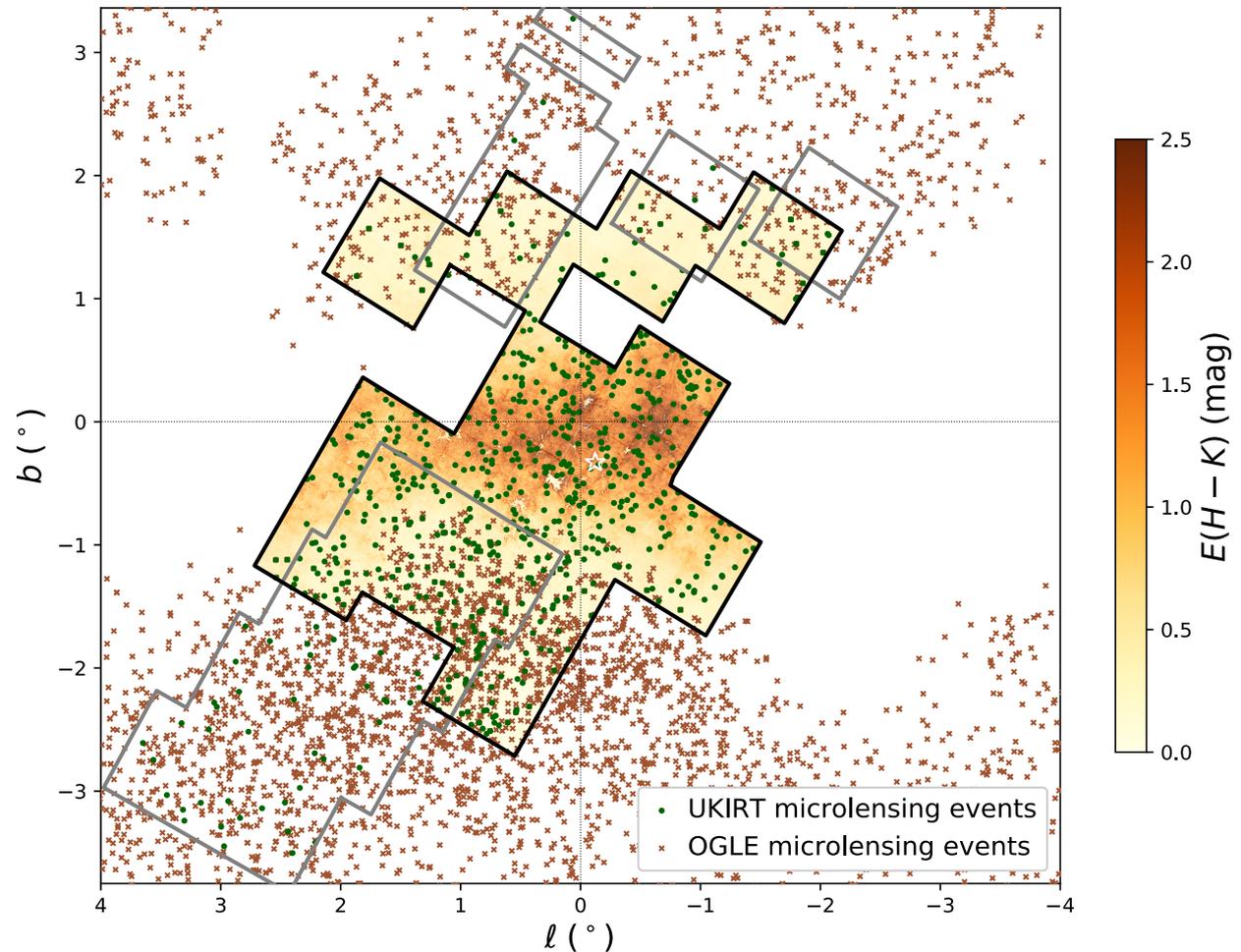
2017: 292 events

2018: 118 events

2019: 214 events

Total: 719 events

(OGLE has ~2000 events per year)



Microlensing Events: UKIRT 2017-2019

UKIRT summary

2015: 15 events

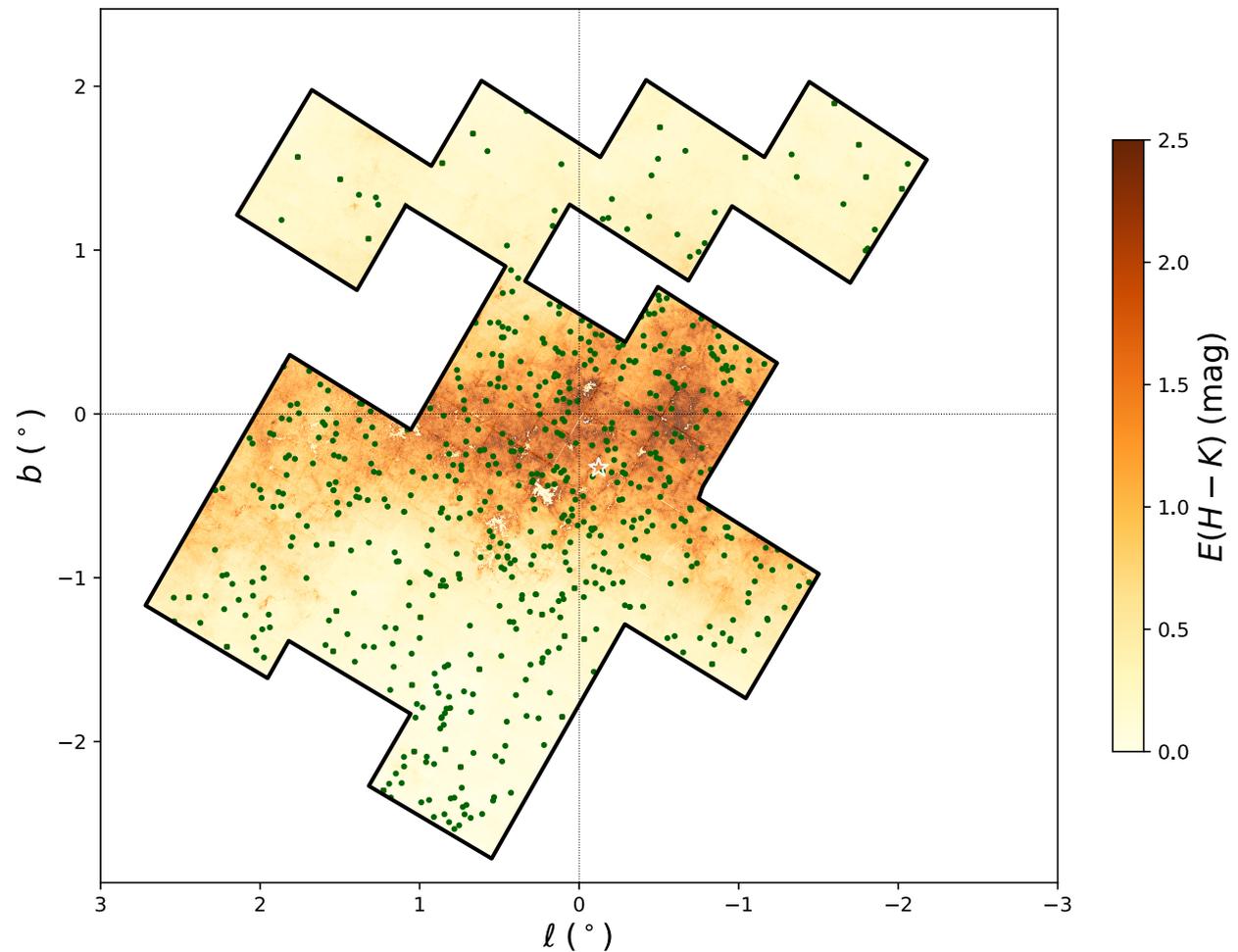
2016: 80 events

2017: 292 events

2018: 118 events

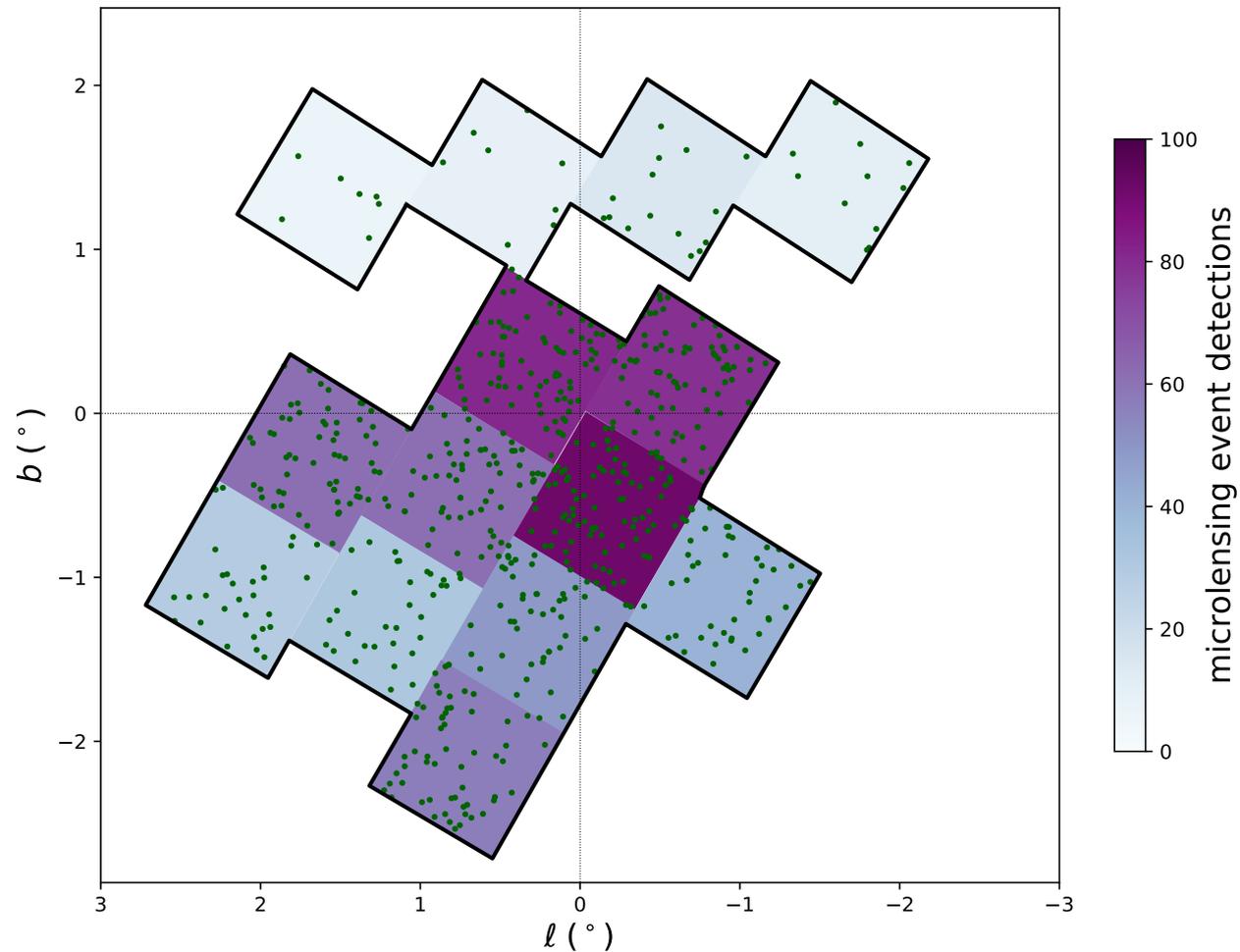
2019: 214 events

Total: 719 events



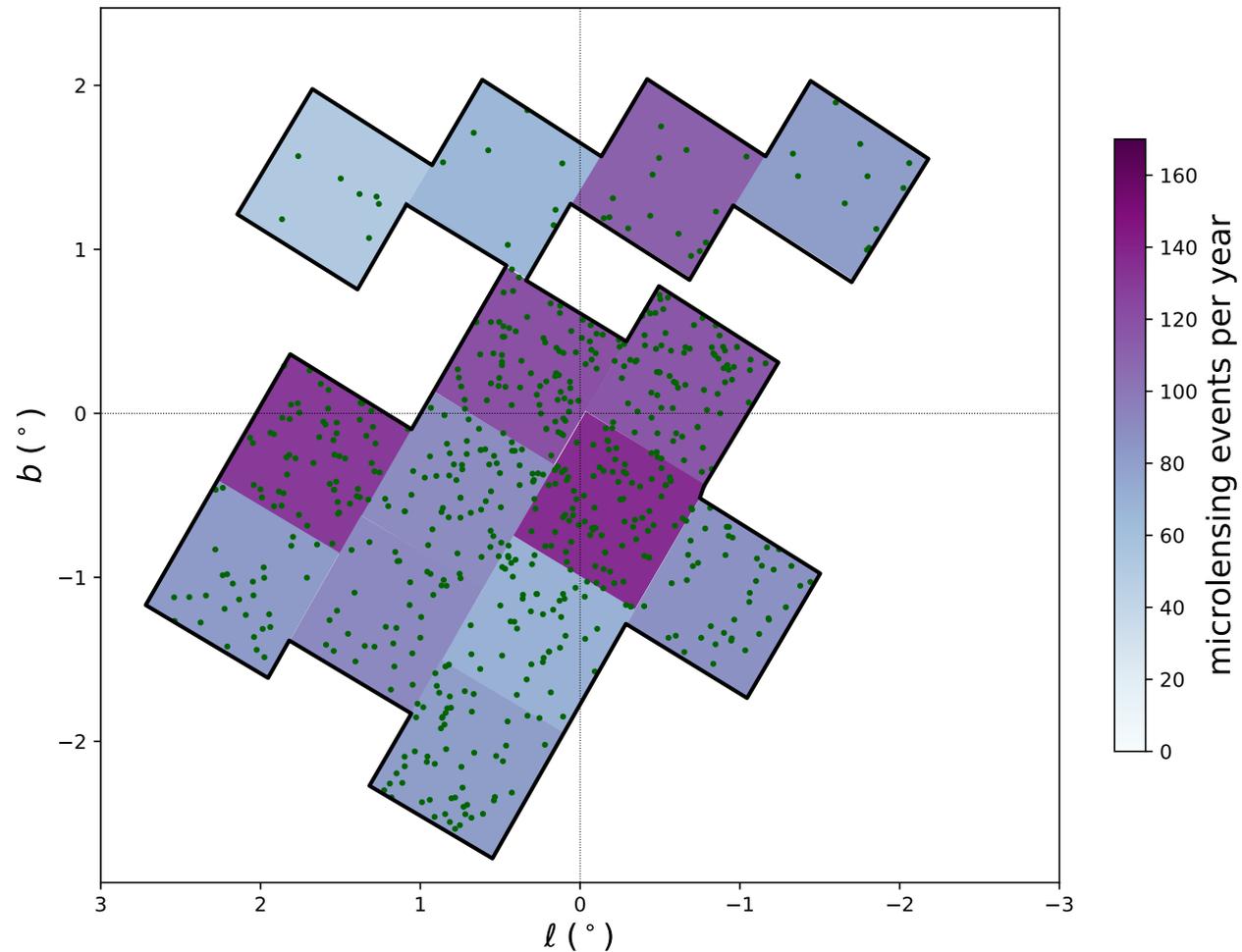
Microlensing Events: Raw Map

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

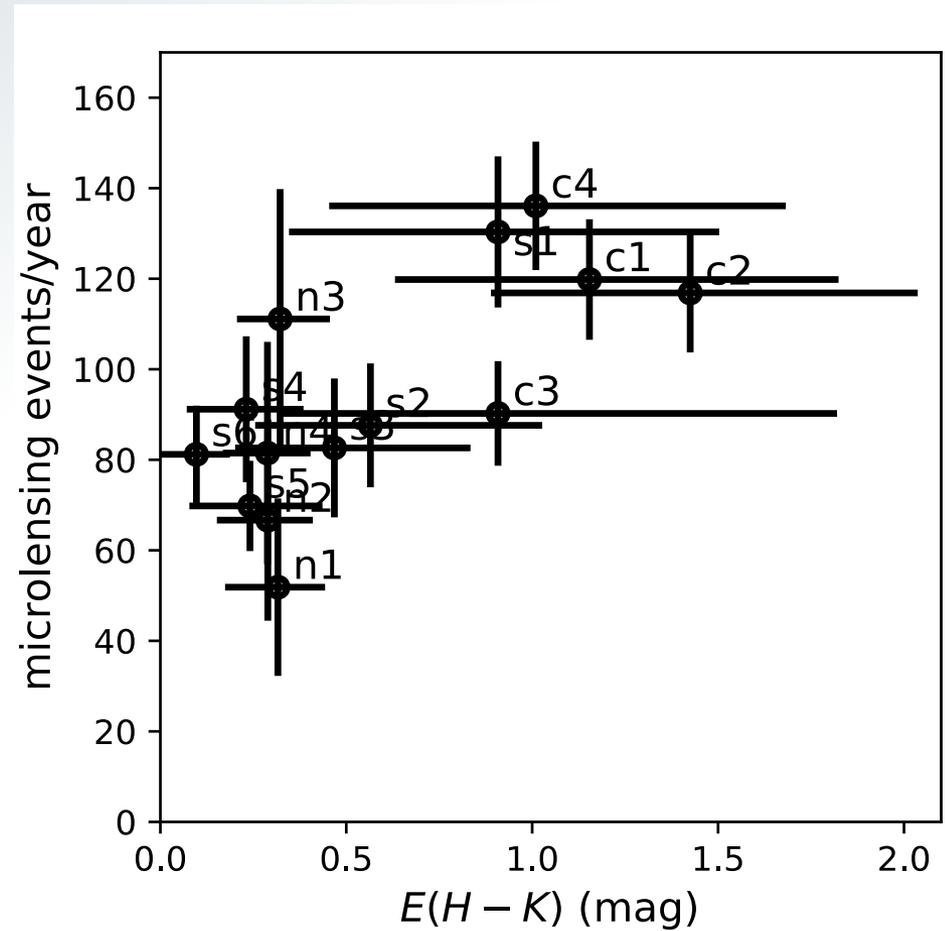
UKIRT results provide an input for survey yield optimization (Penny/Johnson talk).

Roman target field selection must consider several factors:

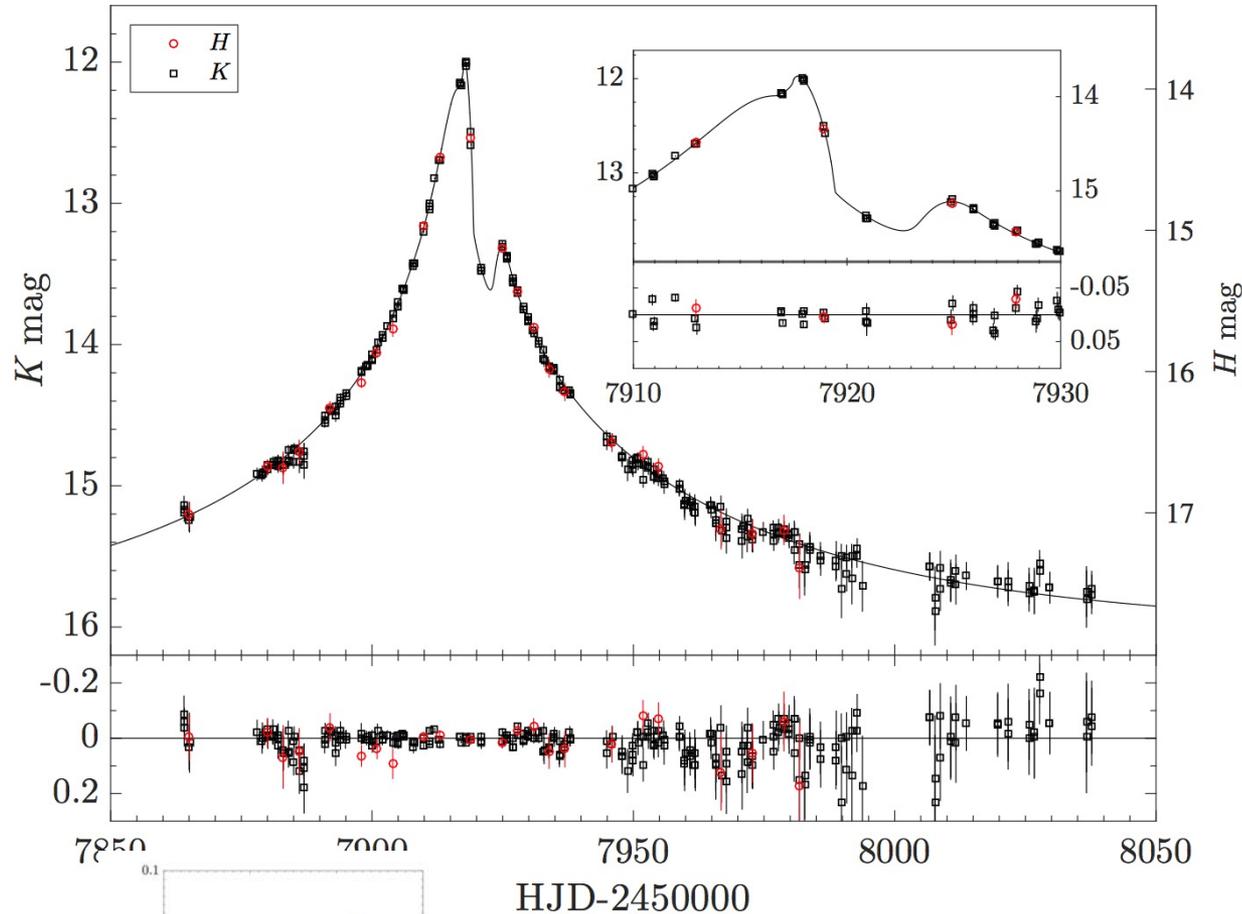
- microlensing event rate
- extinction and, in particular, differential extinction
- overlap with ground-based surveys (optical & near-IR)
- continuity / slew minimization

Bottom line:

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



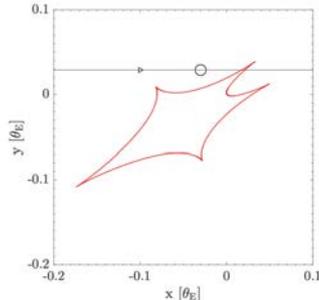
UKIRT-2017-BLG-001b



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_{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

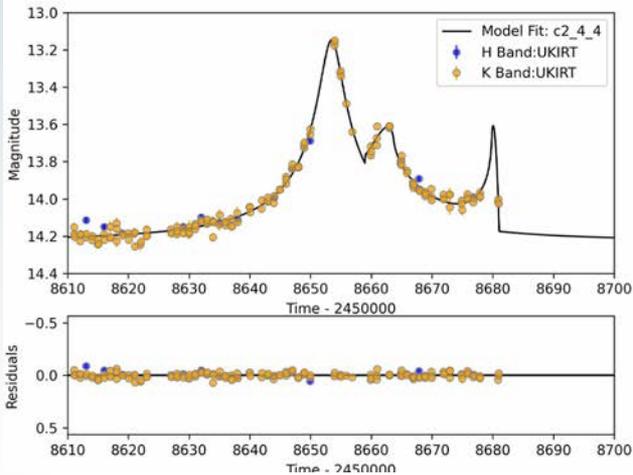
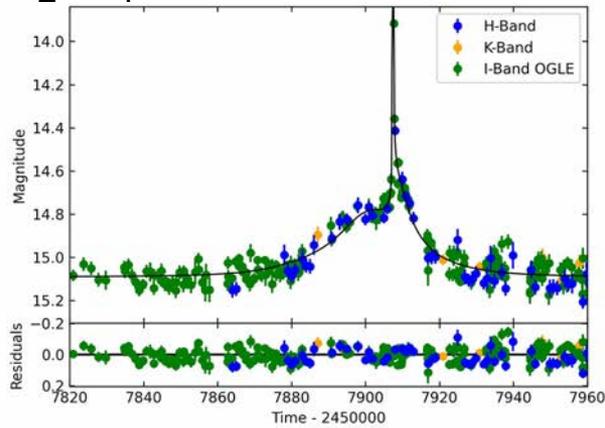
$M_1 [M_\odot]$	$0.81^{+0.31}_{-0.34}$
$M_2 [M_J]$	$1.22^{+0.48}_{-0.51}$
r_\perp [AU]	$3.24^{+0.83}_{-0.91}$
D_L [kpc]	$5.4^{+1.4}_{-1.7}$

Shvartzvald et al. 2018

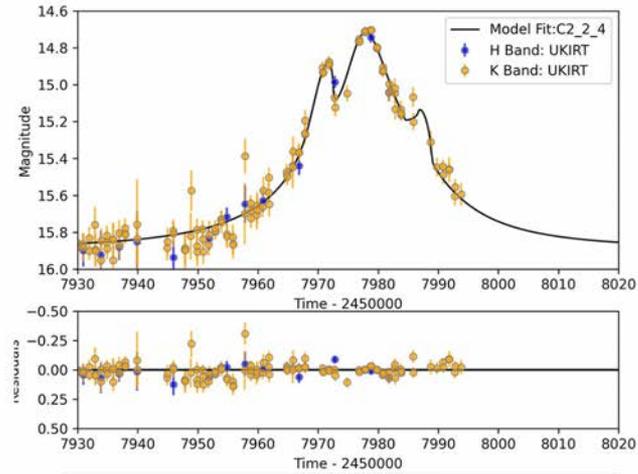


More Binaries/Brown Dwarfs/Planets

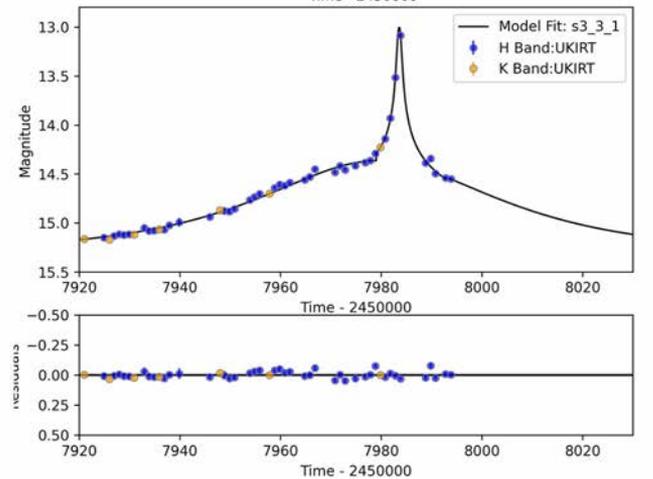
$$M_2/M_1 = 0.21 \pm 0.02$$



$$M_2/M_1 = 0.069 \pm 0.005$$



$$M_2/M_1 = 0.035 \pm 0.006$$



$$M_2/M_1 = 0.87 \pm 0.12$$



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

NASA EXOPLANET ARCHIVE
NASA EXOPLANET SCIENCE INSTITUTE

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Search UKIRT Time Series

This Interactive Visualizer Search allows you to specify subset(s) of UKIRT data to view in an interactive table. To search, select the appropriate operation from the Op column, enter the constraint value in the field provided, and click Submit. Use the Field Selector panel to add or remove search parameters. For additional UKIRT documentation:

- [Column Descriptions](#)
- [UKIRT Information](#)

For best results:

- Use Firefox 15.x or newer and [allow pop-ups](#). Internet Explorer is not supported at this time.
- Select and de-select your desired columns first, then enter your search constraints.
- For assistance, consult the [User Guide](#).

Column Selection

Update Constraint Columns Reset
Select All Visible Select None

Stellar Columns

Microlensing Survey Catalogs

- K2 Campaign 9 Field Overlap Flag
- UKIRT Event Flag
- UKIRT Event ID
- OGLE Event Flag
- OGLE Event ID
- MOA Event Flag
- MOA Event ID

Magnitude Statistics

- Points in Statistics Calculation
- Minimum Value of Light Curve [mag]
- Maximum Value of Light Curve [mag]
- Mean Value of Light Curve [mag]
- Std Dev of Light Curve wrt Mean [mag]
- Median of Light Curve [mag]
- Std Dev of Light Curve wrt Median [mag]
- Number of Points > 5 Sigma from Median
- Fraction of Points > 5 Sigma from Median
- Median Absolute Deviation of Light Curve
- Reduced Chi-squared of Light Curve
- 5-95% Range of Light Curve [mag]

Time Series Lookup

Enter a UKIRT source ID to view its time series, or to generate a download script for all related time series files.

(Sample ID: *ukirt_c_2016_s_33_1_0065104*)

Source ID

Up to 100,000 results will display in the web browser. Results between 100,000 and 5 million must be downloaded by wget script; >5 million requires a bulk download.

Many thanks to the UKIRT facility and the UKIRT Microlensing Team for making these data available.

Include location search around coordinates / object names

Single Location Radius (arcsec):

List Upload: No file selected.

Include column value / range constraints

Description	Column	Op	Column Constraint
Source ID	sourceid	Substring	<input type="text"/>
Survey Year	obs_year	=	2019
Galactic Bulge Region	bulge	Substring	<input type="text"/>
Field ID	field	=	<input type="text"/>
CCD ID	ccdid	=	<input type="text"/>
RA [decimal degrees]	ra	=	<input type="text"/>
Dec [decimal degrees]	dec	=	<input type="text"/>
Start HJD [days]	hjdstart	=	<input type="text"/>
End HJD [days]	hjdstop	=	<input type="text"/>
H-band [mag]	h_mag	=	<input type="text"/>

<https://exoplanetarchive.ipac.caltech.edu/docs/UKIRTMission.html>

<https://exoplanetarchive.ipac.caltech.edu/cgi-bin/TblSearch/nph-tblSearchInit?app=ExoTbls&config=ukirttimeseries>